MCCARRAN INTERNATIONAL AIRPORT
TERMINAL 3
LAS VEGAS, NV

The Pennsylvania State University

Architectural Engineering Senior Thesis Final Report

Evaluation of Underfloor Air Distribution and Displacement Ventilation Systems

April 9, 2008

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Mechanical Option

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McCarran International Airport Terminal 3

Las Vegas, NV

PRIMARY PROJECT TEAM

Owner:	Clark County Dept. of Aviation
Construction Manager:	Bechtel Corporation
Architect:	PGAL, LLC
Structural:	Walter P. Moore
MEP:	JBA Consulting Engineers

PROJECT INFORMATION

Size:	1.8 Million SF
No. of Levels:	5 (Including Basement & Penthouse)
Dates of Construction:	April 2007 - Mid 2012 (Projected)
Delivery Method:	Design - Bid - Build

ARCHITECTURE

-Designed as a unit terminal, to be independent of existing terminals.
-Located on the Northeast portion of the overall airport site.
-Provides (14) new gates serving domestic and international flights, a significant addition to the existing (104) gates at the airport.
-Customs and border patrol areas included for international service.
-A new Automated Transportation System (ATS) station will provide access to the existing Satellite D.
-(2) separate TSA screening areas provided for access to Terminal 3 gates and Satellite D gates. Satellite D remains a fully secure facility.
-Pedestrian access for new parking garage will be provided on Level 1.

STRUCTURAL

-(5) Isolation joints divide the building into (6) structures.
-Foundation made of 3-6' diameter drilled piers 35-75' deep.
-4.5" thick concrete slab over 3" composite metal deck.
-Typical grid spacing = 40' with few exceptions at 28' or 48'.
-Typical girders in the East-West direction will be W33's and Beams spanning North-South will W24's for 40 ft bays W27's for 48 ft bays, and W18's for 28 ft bays.
-Lateral loads are resisted by braced frames.

ELECTRICAL

-New Nevada power yard at central plant will include (4) 15 kV service entrance switchgear sections and service from (2) separate substations.
-Service to be provided by (4) 10 MVA main feeders and (4) 10 MVA dedicated back up feeders.
-(4) 2000 kW/2500kVA, 480/277 V diesel generators with step up transformers are provided with paralleling switchgear for emergencies.

MECHANICAL

-(24) CV AHU's serving electrical substations, (27) SZ VAV AHU's serving concourse and baggage handling/screening, (37) VAV AHU's serving baggage claim, airline operations TSA screening, ticketing, and remaining public spaces.
-SZ VAV and VAV units include demand controlled ventilation by carbon monoxide / carbon dioxide monitoring.
-Served by a new central plant consisting of (5) 2,200 ton centrifugal chillers and (6) 21,000 MBH boilers. An additional boiler and chiller of equal capacity are provided as standby.

JASON A. WITTERMAN

Mechanical Option
http://www.engr.psu.edu/ae/thesis/portfolios/2008/jaw991/

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Acknowledgments

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Clark Country Department of Aviation

Mechanical Design Engineer for Terminal 3
Roger L. Arnold, Jr, P.E., LEED AP

Architect for Terminal 3
PGAL, LLC

Executive Summary

This report is an evaluation of Underfloor Air Distribution (UFAD) and Displacement Ventilation (DV) systems compared to traditional overhead mixing HVAC systems. The areas of application for these systems are the gate holdrooms and airside concourse of Terminal 3 at McCarran International Airport in Las Vegas, NV. The design process is discussed throughout the report and includes load calculations, ventilation requirements, equipment selections, cost comparisons, and other considerations.

Load calculations for Terminal 3 are performed using Trane TRACE software. This software is used to model the spaces of interest based on the existing mechanical system configuration. From here, various load factors are applied to the spaces to determine the load present in the occupied zones. These occupied zone loads are then used to determine the necessary capacity of the redesigned airside systems. An additional 92,532 CFM is required in the spaces served by the UFAD systems; and an additional 36,162 CFM is required in those spaces served by the DV systems.

Outdoor air ventilation rates are calculated in accordance with ASHRAE Standard 62.1-2007. Based on the work performed with regards to this standard, the ventilation effectiveness of both UFAD and DV systems is higher than it is for the existing overhead mixing system. As such, supply outdoor air flow rates required at the outdoor air louvers can be reduced by 52,677 CFM.

Unfortunately, the redesigned system has an associated increase in first cost. This is partly due to the requirement of nine additional air handlers, and partly due to the need for additional terminal units and diffusers within the various spaces. The total increase in first cost is approximately $1,051,280. Potential changes in annual operating costs are also analyzed based on simulations performed in TRACE. Even with reduced outdoor air flow rates and increased economizer operation, annual operating costs still increase due to the larger amount of supply air required. This increase in operating cost is approximated as $158,650 per year. Given the large size of Terminal 3, these costs are relatively minimal compared to the total building costs. Regardless, these increases are not ideal and detract from the potential benefits of the system.

Since the UFAD system will require an underfloor air plenum, an access floor will be installed in the gate holdroom areas. This will require some structural modifications to ensure that a smooth transition can be made from the raised floor to the adjacent existing floor. While the structural impacts of the raised floor are within reason, there are some architectural impacts that are not ideal. Furthermore, the raised floor has a substantial cost of about $985,000 associated with it.

An acoustical analysis is also performed with regards to noise from mechanical system fans. This analysis indicates that the redesigned system will allow for the removal of existing sound attenuators and duct lagging in the area of redesign. The removal of this equipment results in an estimated savings of $45,000 in initial costs.

In general, the replacement of the existing overhead distribution system is not recommended. While there are potential benefits to UFAD and DV systems, they are not appropriate for a facility of this nature. They may, however, be appropriate for other building types.

Architectural Background

Terminal 3 is a 1.8 million SF facility being developed on the northeast portion of the airport site. It will be a "unit" terminal at McCarran International Airport, as it will not be dependent on the existing terminals. The new terminal will provide 14 new gates serving both domestic and international flights. As a result, Terminal 3 will also include customs and border patrol services. Figure 1 shows the location of Terminal 3 relative to the remainder of McCarran International Airport, while Figure 2 shows an exterior rendering of the terminal. Terminal 3 is pictured to the lower right of this rendering, with Satellite D appearing to the left. In the distance, one can see the Las Vegas Strip.

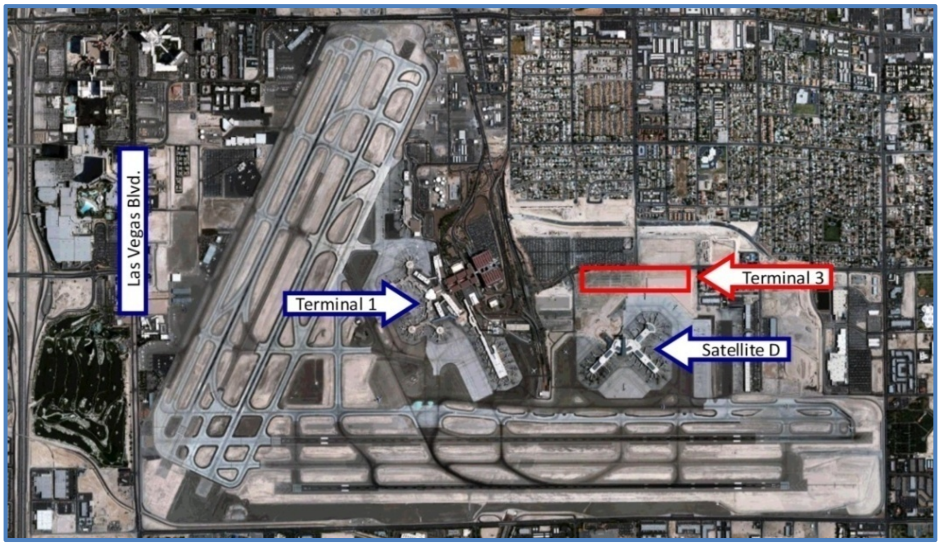

Figure 1: McCarran International Airport Site Plan

Figure 2: Exterior Rendering of Terminal 3 (Courtesy of PGAL, LLC)

Terminal 3 consists of five levels. The below grade basement level includes mechanical and electrical rooms, storage, and Automated Transportation System (ATS) maintenance areas. Level 0 is below grade on the airside of the terminal, and at grade on the landside. It includes baggage claim, customs, an ATS station serving Satellite D, and back-of-house support facilities. This level also contains TSA passenger screening as Satellite D is a fully secure building. Level 1 is at grade on the airside of the terminal and above grade on the landside. It houses the baggage screening systems, airline support area, and other back-of-house facilities. This level is fully secure with the exception of a landing connecting Level 0 and Level 2. This landing will provide access from a new parking garage to be built with Terminal 3. Level 2 contains the new gates, concessions, gaming areas, concourses, ticketing counters, offices, and additional back-of-house facilities. Level 3 of the terminal consists only of mechanical penthouse spaces.

Special attention is drawn to the requirement for full separation of secure and non-secure areas of the new terminal. The following terms are used throughout this report, and are defined here for clarification. The landside portion of the terminal refers to the unsecure portions of the terminal that do not require one to first pass through Transportation Security Administration (TSA) screening areas. The airside portion of the terminal refers to those areas that can only be accessed after having passed through TSA screening lanes.

A new central plant is being constructed to serve Terminal 3. This central plant will be located to the east of the terminal. As stated before, Terminal 3 also includes an ATS station with a tunnel connecting the terminal to the existing Satellite D facility.

Mechanical Systems Background

Waterside Cooling Equipment Summary

A peak cooling capacity of 11,000 tons is provided by a variable primary flow chilled water system. This peak capacity is supplied by five 2,200 ton centrifugal chillers. An additional 2,200 ton centrifugal chiller will be provided as standby for a total of six chillers. Three variable flow chilled water pumps are provided to serve the cooling load, with an additional chilled water pump provided as standby. This results in a total of four chilled water pumps. These pumps are horizontal split case to maintain consistency with the existing central plant. The pumping arrangement is such that the chilled water pumps are decoupled from the chillers. Therefore, any chilled water pump or group of chilled water pumps can operate with any chiller or group of chillers.

The condensing water system for the central plant consists of field erected concrete cooling towers. There are a total of six cells corresponding to the six chillers. Again, five of the cooling towers are provided to serve the cooling load, and one additional cell is provided as standby. The condenser water system is a constant flow system, with five condenser water pumps serving the condenser water load. An additional condenser water pump is provided as standby for a total of six condenser water pumps. Similar to the chilled water pumps and chillers, the condenser water pumps are decoupled from the cooling towers. This allows for any one condenser water pump or group of condenser water pumps to operate with any one cooling tower or collection of cooling towers. Variable Frequency Drives (VFD's) will be included on the cooling tower fan motors to maintain appropriate condenser water temperatures.

All chillers, cooling towers, and heat exchangers have associated isolation valves. When a given chiller or cooling tower is energized, the respective isolation valve shall be open. In contrast, when a given chiller or cooling tower is de-energized, the respective isolation valve shall be closed. Similarly, when a heat exchanger is to be in operation, the associated isolation valve shall open. When a heat exchanger is no longer in operation, the isolation valve shall be closed. The plant itself is also provided with valves to isolate it from the remainder of the system. These valves are pneumatic, and controlled locally within the plant. The Building Management System (BMS) is alarmed in the event the plant isolation valves are closed.

The chilled water system is designed with three potential operating modes. These include mechanical refrigeration, chilled water return pre-cooling, and waterside free cooling. These operating modes are controlled by several operating mode system valves as shown in Figure 3: Chilled Water Schematic, and Figure 4: Condenser Water Schematic. Table 1 indicates the position of these system valves for the various operating modes. A total of two plate and frame heat exchangers are provided for chilled water return pre-cooling and waterside free cooling. Since the chilled water return pre-cooling mode will require the use of condenser water at two separate temperatures, the basin is divided by two sluice gates. When closed, these gates create two separate water basins served by different cooling towers.

Operation Mode	Chilled Water Valves				Condenser Water Valves	
	V-1	V-2	V-3	V-4	V-5	V-6
Mechanical Refrigeration	Open	Closed	Closed	Closed	Open	Open
Chilled Water Return Pre-Cooling	Closed	Open	Closed	Closed	Closed	Closed
Waterside Free Cooling	Closed	Closed	Open	Closed	Open	Open

Table 1: Chilled Water and Condenser Water System Control Valve Matrix

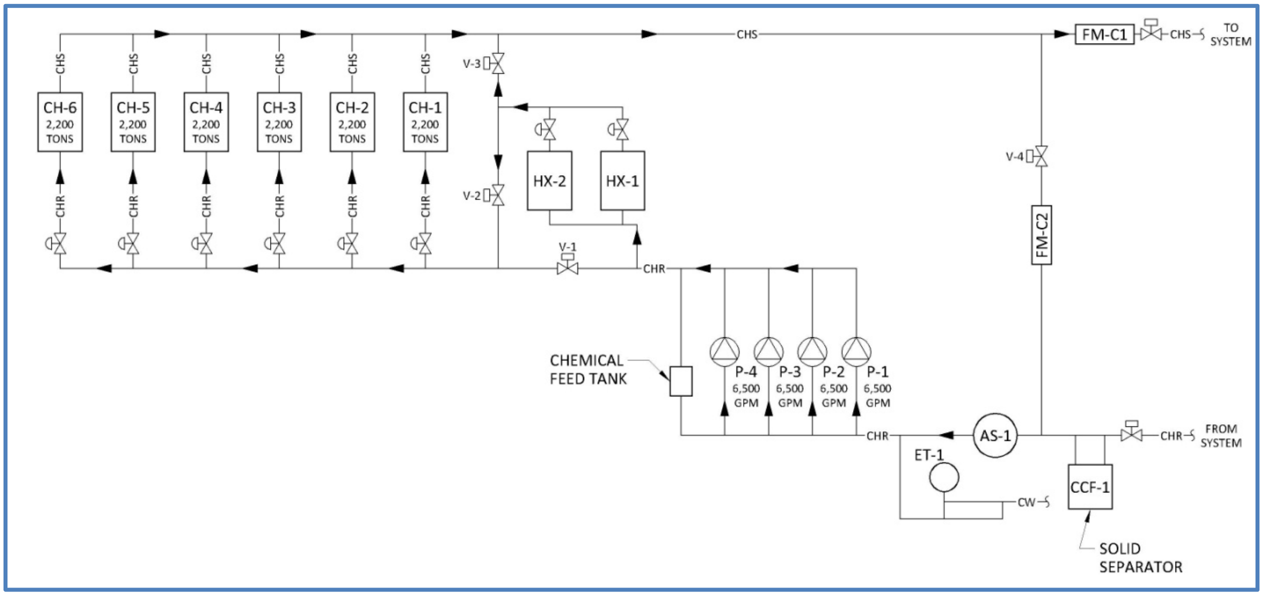

Figure 3: Chilled Water Schematic

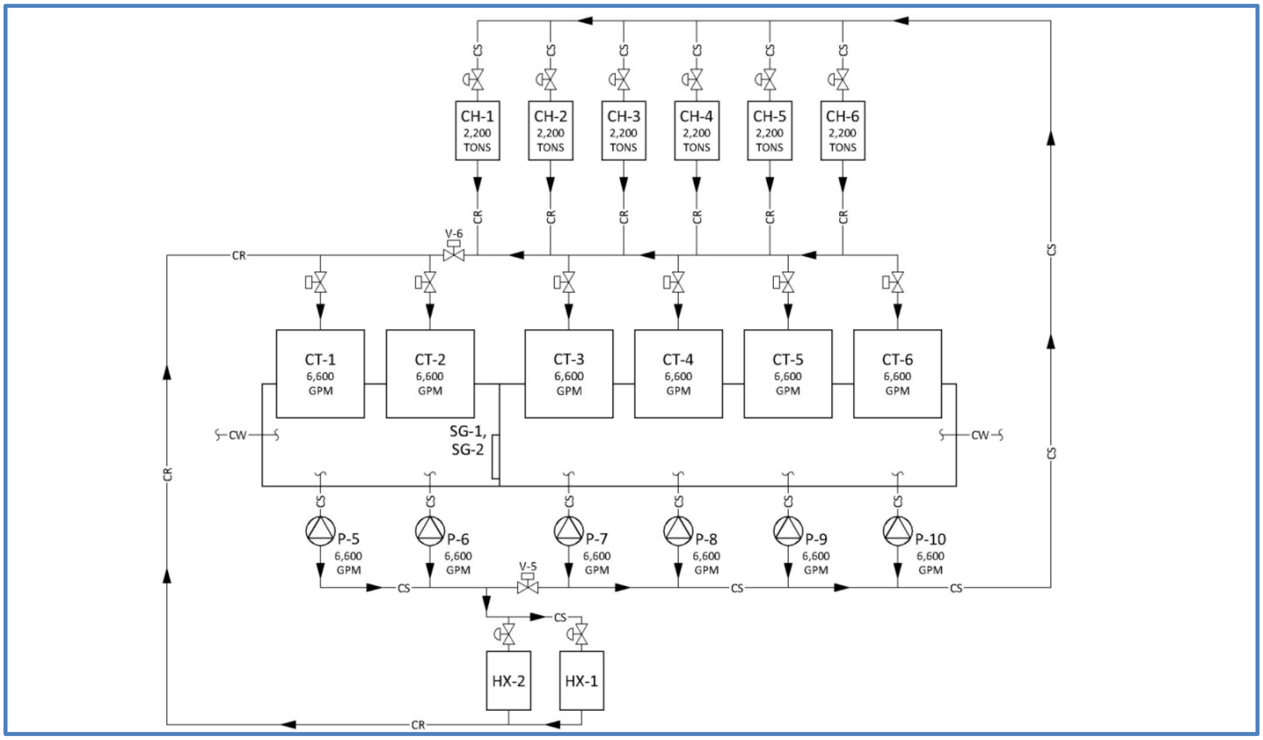

Figure 4: Condenser Water Schematic

Mechanical Refrigeration

In this mode, the chillers are operated as required to maintain the plant leaving water temperature setpoint of 42°F. Chilled water pumps are also operated as required to satisfy the chilled water demand. In addition, the cooling towers are staged as required to satisfy the condenser water demand of the chillers. The condenser water supply setpoint is set to 85°F.

Chilled Water Return Pre-Cooling

In this operating mode, chilled water return water (CHR) passes through one or both of the heat exchangers (HX-1, HX-2) prior to entering the chillers. Operation in this mode requires that the sluice gates (SG-1, SG-2) be closed to separate the cooling tower basin into two basins. One portion of the basin makes condenser water for the chillers at a condenser water supply temperature of 52°F, while the other portion makes water as cold as ambient conditions will allow for use in the heat exchangers. The desired condenser water supply temperature for use in the heat exchangers is 38°F. The chillers are utilized in this mode to provide the remaining cooling required that is not performed in the heat exchangers. The portion of the system making condenser water for the chillers includes cooling towers CT-3, CT-4, CT-5, and CT-6; as well as condenser water pumps P-7, P-8, P-9, and P-10. No chillers are utilized by this side of the system. Any chiller and any chilled water pump are permitted to operate in this mode. The portion of the system providing colder condenser water for the heat exchangers is served by cooling towers CT-1, and CT-2; as well as condenser water pumps P-5, and P-6.

When seasonal weather permits this mode of operation to be successful, the sluice gates will be manually closed. The condenser water pump headers are also separated, but through automatic control. The condenser water system is now divided into a hot system for use by the chillers, and a cold system for use by the heat exchangers. When the outside air wet bulb temperature falls to 10°F below the chilled water return temperature, the BMS shall index the system to operate in the chilled water return pre-cooling mode. At this time, the isolation valves on both the chilled water and condenser water sides of the heat exchangers are opened. The BMS shall then position system valves as indicated in Table 1. When the cold system condenser water temperature is 2°F less than the chilled water return temperature for duration of five continuous minutes, the BMS places the chilled water system into mechanical refrigeration mode. Once the system valves are positioned to allow for full chilled water return flow to the chillers, the BMS closes all isolation valves on the heat exchanger.

Waterside Free Cooling

In this mode, all chillers are de-energized. The cooling towers operate in sequence to make water for the heat exchangers that will maintain the plant leaving water temperature setpoint. The condenser water supply setpoint is set to 38°F. Chilled water pumps are again staged as necessary to satisfy the chilled water demand of the system.

Operation in this mode is set when the outside air wet bulb temperature falls to 38°F. At this time, the BMS shall stage off any chillers that are in operation and open the isolation valves on both the chilled water and condenser water sides of the heat exchanger. The BMS shall then position system valves as indicated in Table 1. If the chilled water supply temperature rises to 49°F for five minutes, the BMS shall place the chilled water system into the chilled water pre-cooling mode.

Waterside Heating Equipment Summary

A peak heating capacity of 105,840,000 Btu/h is provided by a primary / secondary heating hot water system. This peak capacity is supplied by six 21,000 MBH flexible water tube boilers. The total input capacity of these boilers is 126,000 MBH, and the boilers have an efficiency rating of 84%. The resulting output capacity is therefore 105,840,000 Btu/h. An additional 21,000 MBH input boiler is provided as standby for a total of seven boilers. The primary heating hot water loop includes six constant flow hot water primary pumps to serve the heating load. An additional hot water primary pump is provided as standby. The secondary heating hot water loop includes three variable flow hot water secondary pumps to serve the heating load. Again, an additional hot water secondary pump is provided as standby. Both primary and secondary hot water pumps will be horizontal split case piped with common headers to allow the operation of any pump with any boiler.

Figure 5 shows the schematic for the heating hot water system. Similar to the chilled water system, the equipment on the heating hot water system also has associated isolation valves. When a boiler is energized, the associated isolation valve shall be open. When a boiler is de-energized, the respective isolation valve shall then be closed. The heating hot water system also has plant isolation valves that allow the plant to be isolated from the remainder of the system. These valves are pneumatic, and controlled locally within the plant. A closed plant isolation valve is set to alarm the BMS.

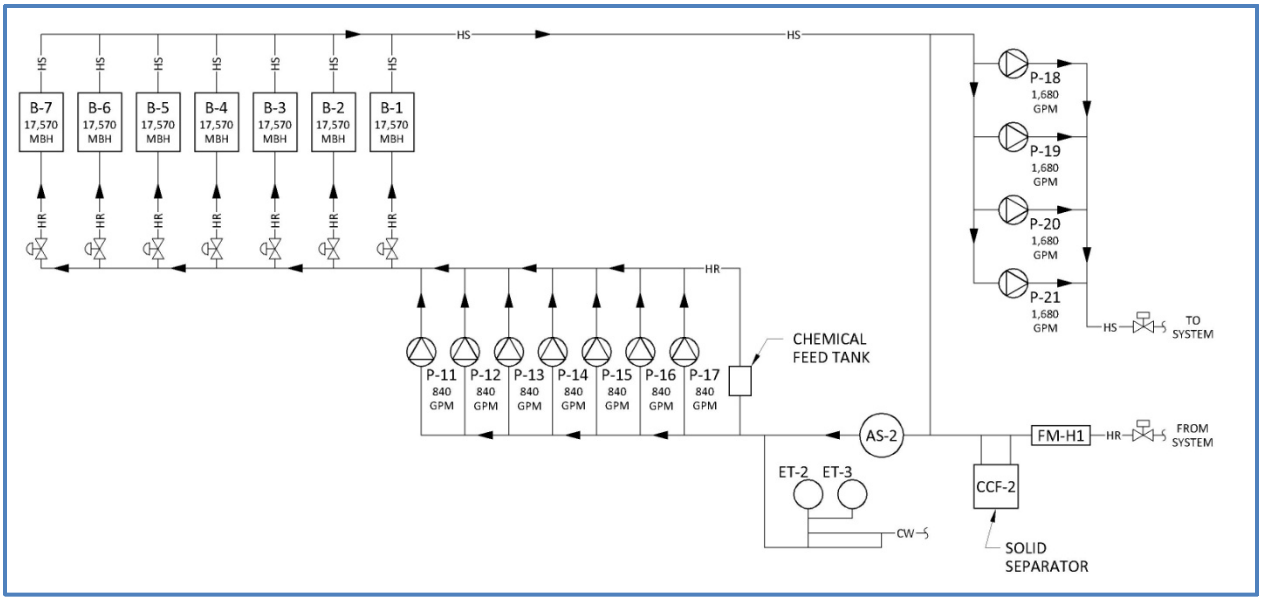

Figure 5: Heating Hot Water Schematic

The heating hot water supply temperature setpoint is 200°F. The building heating load demand is determined through the measurement of heating hot water flow rate, as well as supply and return temperatures of the heating hot water. These flow meters are identified on the heating hot water system schematic.

Direct / indirect evaporative coolers are provided at the central plant to provide conditioned and filtered make-up air to the boiler room. The VFD's on these evaporative coolers will be controlled by the BMS to provide the required quantity of combustion air based on the number of boilers to be operating. Once this is achieved, the BMS opens the lead boilers heating hot water isolation valve and the lead heating hot water primary pump. Next, the lead heating hot water secondary pump is energized.

If the boilers in operation have been on for 20 minutes and the heating hot water supply temperature is 5°F or less below the setpoint for five continuous minutes, then additional boilers shall be staged on. In contrast, if the system heating load decreases below the capacity of an online boiler for five continuous minutes, then the boiler with the highest total accumulated run time is disabled.

Airside Equipment Summary

Terminal 3 is served by 88 air handling units, with an additional three units serving the central plant. With the exception of those units serving the baggage handling areas, electrical substations, and chiller rooms; all of these air handling units have a carbon dioxide monitoring system. Similarly, the air handling units serving the baggage handling areas include a carbon monoxide monitoring system due to the operation of combustion engine driven baggage tugs. Each of these sensors allows for demand controlled ventilation in accordance with ASHRAE Standard 62.1-2007 Section 6.2.7. Almost all air handling units include variable speed drives as well. The exceptions to this are the units serving the electrical substations (AH-62 through AH-85), and those serving the chiller rooms at the central plant (CUP AH-1, CUP AH-2).

The landside concourse and baggage handling / screening areas are served by a total of 27 Single Zone Variable Air Volume (SZ VAV) units. As mentioned above, these air handling units are equipped with VFD's to allow for a reduction in airflow during periods of reduced occupancy. A total of 37 VAV air handling units are used to serve baggage claim, airline operations, TSA screening, ticketing, holdrooms, and other public areas. The electrical substations are all served by Constant Volume (CV) air handling units. There are a total of 24 CV AHU's to serve the various substations. At the owner's request, IDF / Telecom and other computer rooms are cooled by floor mounted chilled water equipment.

All existing outside air systems are designed in accordance with ASHRAE Standard 62.1-1999. This air will be filtered through MERV 7 pleated pre-filters, and MERV 13 bag type final filters. The air handling units have also been provided with empty filter sections to allow for the addition of activated carbon / media filters, as well as MERV 7 after filters if desired in the future. This has been the case with other air systems recently designed at McCarran International Airport. While carbon filters are currently not installed on any air handling unit at McCarran International Airport, the empty sections have been provided in the event that noxious fumes from jet fuel and other substances become a nuisance inside the facilities.

Toilet, concession, and general exhaust will be routed to roof mounted centrifugal exhaust fans. These fans are located a minimum of 20 feet from any outside air intake, and arranged to avoid contamination of outside air intakes. The louvers for the exhaust and relief air are located on the airside potion of the terminal. The outdoor air intakes, however, are located on the landside portion of the terminal to avoid contamination from exhaust air and the operation of jet engines on the airside portion.

Outline of Mechanical System Redesign

Background Information

The mechanical system redesign for Terminal 3 is focused on the airside portion of Level 2. This area includes the airside concourse and the gate holdrooms. These spaces are located on the south side of Level 2, and are part of a secure area. In other words, this area can only be accessed by those who have passed through the TSA screening area. Figure 6 highlights the spaces included in the redesign, as well as the relative area and location of these spaces.

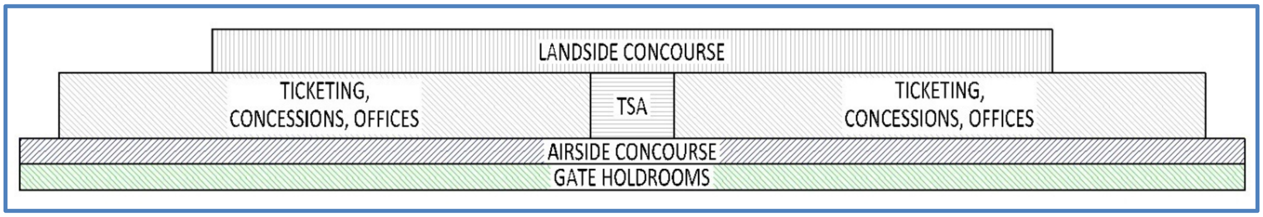

Figure 6: Level 2 Key Plan

As mentioned earlier, Terminal 3 includes 14 new airline gates to better serve passengers through McCarran International Airport. Each of these gates has a respective holdroom providing seating to those waiting to board a plane. Since many of these gates serve reasonably large aircraft, there can be a significant amount of people in a holdroom at a given time. This tends to result in fairly crowded holdrooms, and a high occupant density per square foot. These gate areas are all connected through the airside concourse, which is also a secure area. This concourse area is provided mostly for public circulation, but includes some fixed seating for concessions and gaming areas. Figure 7 shows an interior rendering of the space. On the left, a typical airline gate is shown. This includes the seating for the holdrooms, as well as the actual loading area. In the center of the rendering, the airside concourse is shown. Finally, the various concessions and other tenant spaces are shown to the right.

Figure 7: Interior rendering of typical gate holdroom and airside concourse. (Courtesy of PGAL, LLC)

The ceiling slope is also an important aspect of this space. The low side of the ceiling, located in the holdroom space is approximately 12'-6" above finished floor. From here, the ceiling slopes up to a height of 30'-6" above the floor. This results in a large volume space.

The existing mechanical system in this area is a traditional overhead mixing air distribution system. The gate loading areas and hold rooms are all served by linear ceiling diffusers, whereas the concourse area is served by high sidewall nozzle diffusers. Air is supplied to these spaces by numerous air handling units located in either the level 2 mechanical rooms, or the level 3 penthouse spaces. The units are zoned so that each one serves a combination of holdrooms, airside concourse, and concessions. Temperatures within the spaces are maintained by VAV terminal units, and sensors located in the various rooms.

Design Goals

The main design goal for this space is to create an acceptable indoor environment. This includes a high level of thermal comfort and indoor air quality. The existing system meets these requirements by providing fairly large quantities of conditioned air to the spaces. However, these high quantities of air also result in higher energy consumption and annual costs. This is especially true when the amount of outdoor air required is taken into account. In an effort to help minimize the energy consumption associated with the outdoor air flow rates, the spaces include carbon dioxide sensors that allow for the reduction of outside air quantities. Ultimately, the main goal of any system in this area should be a balance of occupant satisfaction and energy consumption. This is problematic because increasing one of these variables typically causes a corresponding sacrifice in the other variable.

System Selection

Preliminary research indicates that Underfloor Air Distribution (UFAD) mixing systems and Displacement Ventilation (DV) systems are capable of meeting the design goals listed above. In order to learn more about each of these systems, they will both be analyzed throughout this thesis.

Applicability of these systems is determined mostly by location of the supply air diffusers. Both of these systems involve locating diffusers low in the occupied zone. UFAD diffusers are installed in the floor, whereas DV diffusers can either be installed in the floor or low in the wall. For a facility of this nature, there are some concerns with locating diffusers in the floor in that they are subject to significant foot traffic and the collection of debris. That being said, UFAD diffusers are not considered appropriate for the airside concourse. This space has a significant amount of foot traffic, and would therefore be exposed to a large amount of debris. Unlike the open concourse space, the holdrooms have a significant amount of seating for occupants. It is possible that this seating will provide the necessary protection for many if not all of the underfloor diffusers. By locating diffusers under the seats, they are no longer subject to foot traffic. Furthermore, there will likely be a reduction in the amount of debris introduced to the diffuser.

Since floor diffusers are not recommended for the airside concourse, a displacement ventilation strategy will be used in these areas. This design strategy allows for diffusers to be located near floor level, but still within the wall. This strategy would likely not work well in the holdrooms due to a lack of wall surfaces. As shown in Figure 7, the only major wall within the holdroom is the south perimeter wall, which contains expansive amounts of glass. This and other considerations make it quite undesirable to include any air distribution in this wall. The airside concourse, on the other hand, has more interior vertical wall surfaces which may be conducive to displacement diffusers.

Based on the logic mentioned above, the two systems will be investigated with respect to the appropriate areas. The UFAD system will be restricted to the gate holdrooms and associated support spaces. The DV system on the other hand will be utilized in the airside concourse through the use of sidewall diffusers located low in the wall. Throughout the investigation of these systems, the applicability of displacement ventilation systems to the holdrooms is still considered. This is based on the fact that a displacement ventilation strategy could still be incorporated in this space through the use of floor diffusers.

Justification for Investigation

The investigation of these systems is justified based on the fact that research indicates they are capable of meeting the design goals listed previously. Several case studies and design guides have indicated that these two systems are capable of creating a high level of indoor air quality. Traditional overhead mixing systems typically mix the full volume of air within the space, and in the process dilutes any contaminants that may be present. However, both UFAD and DV systems seek to only condition the lower portions of the space. This area is referred to as the occupied zone, and typically reaches to a height of 6-8 feet above the floor level. As a result of only conditioning the occupied zone, the room becomes stratified and contaminants are carried up and out of the occupied zone. This is achieved by supplying cool air at or near the floor level. From here, this air is heated by people and equipment within the space. Due to buoyancy forces, this warmer air is moved upward towards the ceiling. In turn, contaminants in this warmer air are then removed from the space with the return air.

The same research efforts indicated above have also shown that displacement ventilation and UFAD can result in reduced energy consumption. Since air is being supplied directly to the occupied zone, it is supplied at higher temperatures than overhead mixing systems. Consequently, the temperature of the return air from these spaces is also higher. These higher air temperatures result in the potential for increased economizer operation. Furthermore, ASHRAE Standard 62.1-2007 indicates that ventilation effectiveness values for UFAD and DV systems are higher than those for overhead mixing systems. This will likely allow for a reduction in design outdoor air flow required at the outdoor air intake of each air handler, and consequently for further energy savings.

Finally, there is some research that indicates supply air quantities may be lower for each of the proposed systems than for traditional overhead systems. Since only a portion of the loads within the space directly impact the occupied zone, reduced airflows may be used to meet this load. The remaining portion of the load impacts the unoccupied zone, and will only be seen by the system coil. In other words, coil capacity is not expected to decrease but supply air flow rates may. This reduction will be impacted by the portion of the load affecting the occupied zone, and the ΔT of the air.

Calculation of Revised Space and System Loads

Background and Explanation of Load Differences

The first step in the design process is to determine the total loads that the system must be capable of handling. It is important to note that there will be some load differences between systems, since each system will deal with the load in different ways. Despite this, the load sources remain constant regardless of the system type being analyzed. In other words; the envelope construction, occupant density, lighting, and other equipment will remain constant for each space throughout the analysis. However, since UFAD and DV systems are only conditioning a portion of the space, the loads that must actually be conditioned by the supply air can be reduced.

Since UFAD and DV systems only condition the occupied zone within the space, the total space loads are separated into two categories. The first of these categories is occupied zone loads. These loads are present in the first 6-8 feet of the space, and must be conditioned through air supplied directly to the space. The other category is unoccupied zone loads. These loads are above the occupied zone, and as a result of stratification within the space they do not require conditioning by additional supply air flows. Eventually, this warmer air will be removed from the space by the return air fan. A portion of this air will then be exhausted, and the remainder will be returned to the air handling unit. Since some of this air is recirculated to the cooling coil, the coil must have enough capacity to handle the loads of both the occupied and unoccupied zones.

Trane TRACE 700 is used for simulating all the loads that will impact each system. This software is capable of accounting for all of the factors that generate a cooling load within the space. In order to create an accurate model, the software takes into account the components that comprise the building envelope. This includes the wall and roof assemblies, as well as any wall glazing or skylights. The simulation also takes into account any heat generating equipment in the space such as lighting, computers, or other electrical equipment. Finally, the simulation program takes into account heat generated by occupants within the space. The load from these occupants will play a major factor on the system designs since most of the spaces will be densely occupied. Since TRACE does not have any special procedures for calculating UFAD and DV loads, the simulation is first run based on the use of a traditional overhead VAV system. Once this is achieved, the load results can be manipulated by hand to represent the loads within the occupied zone of each system.

Both outdoor and indoor design conditions are important for properly estimating design loads within Terminal 3. Table 2 summaries the outdoor design conditions listed in ASHRAE Fundamentals, as well as those used by the mechanical design engineer for Terminal 3. Table 2 indicates that the actual design values for cooling vary somewhat significantly from those suggested by ASHRAE. The mechanical design engineer stated that the owner specifically requested the use of higher ambient conditions than those listed in ASHRAE.

The use of higher ambient conditions was done for a couple of reasons. The first reason is a result of site factors at McCarran International Airport. The site itself is comprised of several buildings that can be considered relatively small compared to the size of the overall site. The remaining portions of the site consist mostly of runways and aprons that are paved with 18” thick concrete. This incredibly large area of concrete creates a heat island at the facility. As a result, the local outdoor conditions at the airport site are actually higher than those of the surrounding areas. A second reason for the use of higher design cooling values is the fact that occupant comfort is crucial. This is especially true in the event of delayed flights. Flight delays are a possibility at any airport, and often result in overcrowded holdrooms at airline gates. The increase in cooling dry bulb temperature and mean coincident wet bulb temperature help to ensure that the mechanical system is capable of dealing with the space loads to an extent that occupant comfort is not compromised. In general, the changes to the outdoor design conditions are considered to be good design practice for a facility of this nature. As a result, these conditions are carried through into the redesigned load analysis.

Annual Cooling Design Conditions					
ASHRAE 2005, 0.4%			Actual Design Values		
Cooling DB	MCWB	Evaporation WB	Cooling DB	MCWB	Evaporation WB
108.4 °F	66.9 °F	71.4 °F	115 °F	74 °F	77 °F
Annual Heating Design Conditions					
ASHRAE 2005, 99.6%			Actual Design Values		
Heating DB			Heating DB		
28.9 °F			27 °F		

Table 2: Design Outdoor Conditions

Table2 also shows an increase in evaporation wet bulb temperature. This value is used for the design of the cooling towers, and has been increased due to the layout of the cooling towers themselves. Each cooling tower has only one air inlet, and due to the architecture of the building they are forced to be located adjacent to the cooling tower basin. This basin is located between the cooling tower stack and the central plant itself. Essentially this area is an approximately 20'-0" wide separation between the two building components. The inlet is also located approximately 24'-0" from the top of the structure. That being said, air entering the cooling tower must pass over the basin, and is therefore subject to higher humidity levels. Furthermore, the large air quantities that pass through the cooling tower have the potential for entrainment back to the fan inlet. As such, the increase in evaporation wet bulb temperature is warranted for both the existing and redesigned systems.

Summer Design Conditions	
DB Temperature	Relative Humidity
75 °F	50% or less
Winter Design Conditions	
DB Temperature	Relative Humidity
72 °F	50% or less

Table 3: Indoor Design Conditions

Indoor design conditions for the area of redesign are listed in Table3. These conditions are consistent with those provided by the design engineer for the existing system. There is one exception to these design conditions, in that during the summer season all baggage handling areas are designed to be maintained at 80 °F. This is an attempt to conserve the energy required to cool this space, which is often open to the ambient outdoor conditions due to the nature of the space. These spaces are not public areas, and therefore occupant comfort is of less concern. These baggage handling areas are not part of the redesigned area, and therefore all of the redesigned spaces are intended to meet the criteria of Table 3.

Load Factors for Underfloor Air Distribution Systems

Once the initial loads are determined for the entire space, the loads can be broken down into those affecting the occupied and unoccupied loads. This step is perhaps the most critical in determining the size of the system required for each space. Unfortunately, this also appears to be an area where minimal prior research exists. Throughout the duration of this thesis, many resources were consulted in an attempt to determine appropriate load factors for the occupied and unoccupied zones. Oftentimes, it was quite difficult to locate and obtain this data. Once the data was obtained, it was realized that the load factors from each of these resources varied significantly. In the end, this data is open to personal interpretation. This is likely the reason why there has been a great amount of debate with regards to the potential benefits of UFAD.

In order to determine reasonable load factors for each system, the minimum and maximum values for each load component were analyzed. Load factors were then assigned within this range according to personal evaluation and logic. Table 4 shows the various load factors for UFAD systems. Wherever possible, the most reputable data source was used as a basis for design. In the case of UFAD load factors, most of the data is relatively close to data published in various ASHRAE publications. These resources are listed in the References section of this report.

Component of Load	Occupied Zone Load Factors According to Various Research		Occupied Zone Load Factor Used for Design
	Minimum	Maximum	
Occupants	0.65	0.75	0.75
Lights (Fluorescent)	0.60	0.70	0.67
Equipment	0.67	0.70	0.67
Envelope Conduction	0.70	0.82	0.77
Envelope Solar	0.70	1.00	1.00

Table 4: Load Factors for Underfloor Air Distribution Systems

Load Factors for Displacement Ventilation Systems

Similar to UFAD systems, the loads for the displacement ventilation systems must be assigned to either the occupied or unoccupied zone. Once again, there is also a minimal amount of prior research for load factors relative to DV systems. The process of determining the load factors for the DV systems was done using an approach similar to the UFAD systems. Table 5 shows the various load factors for DV systems. Again, every effort is made to ensure that the most reputable data source is used as a basis for design. In the case of the displacement ventilation load factors, all of the occupied zone load factors are taken from the ASHRAE design guide for displacement ventilation systems. More information about this design guide is included in the References section of this report.

Component of Load	Occupied Zone Load Factors According to Various Research		Occupied Zone Load Factor Used for Design
	Minimum	Maximum	
Occupants	0.295	0.670	0.295
Lights (Fluorescent)	0.132	0.500	0.132
Equipment	0.295	0.500	0.295
Envelope Conduction	0.185	0.820	0.185
Envelope Solar	0.185	1.000	0.185

Table 5: Load Factors for Displacement Ventilation Systems

Calculation Procedure and Summary of Resultant Loads

Once the load factors for each system type are determined, the redesigned loads are relatively simple to calculate. To begin with, the loads outputs from TRACE are broken down according to the components listed in Table 4 and Table 5. Once this is done, the existing loads are simply multiplied by the appropriate load factors. These resulting values are the loads present in the occupied zone that will require conditioning with supply air. The remaining load will be extracted by the return air and conditioned at the coil, but will not require the introduction of supply air into the space. Table 6 and Table 7 summarize the differences between the occupied zone loads for the various systems.

Room Name	Traditional Load [BTU/HR]	DV Load [BTU/HR]	Difference [BTU/HR]
Gate 01 Airside Concourse	398,662	92,310	306,352
Gate 02 Airside Concourse	295,578	75,095	220,483
Gate 03 Airside Concourse	274,544	69,348	205,196
Gate 04 / 05 Airside Concourse	626,301	143,702	482,599
Gate 06 / 07 Airside Concourse	291,563	74,352	217,211
Gate 08 Airside Concourse	131,310	33,571	97,739
Gate 09 / 10 Airside Concourse	668,787	153,417	515,370
Gate 11 / 12 Airside Concourse	632,535	144,855	487,680
Gate 14 / 15 Airside Concourse	370,640	90,837	279,803
Total	**3,689,920**	**877,487**	**2,812,433**

Table 6: Comparison of Loads for Traditional and DV Systems

As expected, the results of the load calculations indicate that UFAD and displacement ventilation systems have reduced space loads within the occupied zone. Once again, these load differences are a result of the stratification within the space. In general, the redesigned systems will still see the same traditional load at the coil. The difference now is that only a portion of the load is used to determine the amount of supply air required in the space. These supply air quantities are presented in a later section of this report titled Calculation of New Supply Air Quantities and Temperatures.

Room Name	Traditional Load [BTU/HR]	UFAD Load [BTU/HR]	Difference [BTU/HR]
Gate 01 / 02 Duty Free	2,128	1,501	627
Gate 01 / 02 Interview	3,414	2,455	959
Gate 01 / 02 Sterile Circulation	118,070	109,586	8,484
Gate 01 / 02 Wheelchair Storage	1,556	1,043	513
Gate 01 Holdroom	230,445	189,840	40,605
Gate 02 Holdroom	190,562	144,012	46,550
Gate 03 / 04 Duty Free	1,959	1,382	577
Gate 03 / 04 Interview	3,268	2,350	918
Gate 03 / 04 Sterile Circulation	95,032	88,082	6,950
Gate 01 / 02 Wheelchair Storage	809	542	267
Gate 03 Holdroom	290,694	218,034	72,660
Gate 04 Holdroom	261,214	195,122	66,092
Gate 05 / 06 Duty Free	2,026	1,429	597
Gate 05 / 06 Interview	3,414	2,455	959
Gate 05 / 06 Sterile Circulation	117,734	109,345	8,389
Gate 05 Holdroom	109,760	82,030	27,730
Gate 05 Wheelchair Storage	829	555	274
Gate 06 Electrical	4,136	2,771	1,365
Gate 06 Holdroom	254,805	189,269	65,536
Gate 07 Boarding Corridor	8,189	6,165	2,024
Gate 07 Electrical	3,604	2,415	1,189
Gate 07 Holdroom	131,817	99,207	32,610
Gate 08 / 09 Gaming	40,309	32,212	8,097
Gate 08 Electrical	3,646	2,443	1,203
Gate 08 Holdroom	143,734	108,028	35,706
Gate 08 Wheelchair Storage	8,145	6,009	2,136
Gate 09 Holdroom	161,274	122,905	38,369
Gate 09 Telecomm	901	604	297
Gate 10 / 11 Gaming	43,714	32,328	11,386
Gate 10 Electrical	3,208	2,149	1,059
Gate 10 Holdroom	209,532	158,585	50,947
Gate 11 Holdroom	222,491	168,166	54,325
Gate 12 Electrical	4,198	2,813	1,385
Gate 12 Holdroom	212,170	161,251	50,919
Gate 14 Electrical	3,208	2,149	1,059
Gate 14 Holdroom	207,340	156,964	50,376
Gate 15 Electrical	2,867	1,921	946
Gate 15 Holdroom	203,503	171,198	32,305
Total	**3,305,705**	**2,579,315**	**726,390**

Table 7: Comparison of Loads for Traditional and UFAD Systems

Calculation and Comparison of Outdoor Air Flow Rates

The next step in the design process is to calculate the minimum outdoor air flow rates. This analysis is performed according to ASHRAE Standard 62.1-2007. In order to make comparisons between the existing system and the redesigned system, the analysis is performed separately for each system.

Background and Assumptions

ASHRAE Standard 62.1-2007 Section 6 prescribes two methods for the design of ventilation systems in a building. The analysis contained in this report is based on evaluation by Section 6.2, Ventilation Rate Procedure. In order to analyze the ventilation systems in the building, some assumptions were made. These assumptions are as follows:

Zone Air Distribution Effectiveness

The existing mechanical systems supply cool air through ceiling diffusers in the holdroom spaces, and sidewall diffusers in the airside concourse. In both of these instances, the diffusers are located high above the floor. Therefore, in accordance with ASHRAE Standard 62.1-2007 Table 6-2, $E_z = 1.0$ for all calculations of existing systems. This means that $V_{oz} = V_{bz}$ for these calculations.

The redesigned mechanical systems, on the other hand, will supply cool air through floor diffusers in the holdroom spaces. The diffusers in the airside concourse will still be located in the wall, but they will be located near floor level. As a result, ASHRAE Standard 62.1-2007 Table 6-2 indicates that $E_z = 1.2$ for both the UFAD and displacement ventilation systems.

Zone Primary Airflow

ASHRAE Standard 62.1-2007 Section 6.2.5.1 states that for VAV systems, V_{pz} is the design minimum airflow of the VAV terminal unit. The existing construction documents indicate that this design minimum is 50% of the maximum airflow for all terminal units in the area of focus. This same design minimum airflow will be assumed for the redesigned system.

Occupant Diversity

It is assumed that the occupant diversity, D, is equal to 1.0 for both the existing and redesigned systems. As a result, ASHRAE Standard 62.1-2007 Section 6.2.5.3 states that $V_{ou} = \Sigma V_{bz}$ for all calculations.

System Ventilation Efficiency

The system ventilation efficiency may be found using ASHRAE Standard 62.1-2007 Table 6-3, or alternatively through the use of Appendix A in the standard. This alternative method is used in accordance with the notes for Table 6-3 of the standard. This note states that the values listed in Table 6-3 may result in unrealistically low values for high values of Z_p. Since many of the systems included in the analysis have fairly high Z_p values, all calculations done in this analysis were performed using the equation in Appendix A of the standard.

Exhaust Ventilation

Some spaces require exhaust airflow be provided in accordance with ASHRAE Standard 62.1-2007 Table 6-4. Inspection of the design documents indicates that the existing design conforms to these minimum exhaust rates. Although these spaces will be rezoned, the exhaust systems will not be modified during the redesign. In turn, the spaces will remain compliant with Table 6-4 of the standard. In addition, Section 6.2.8 of the standard states that there is no minimum outdoor air requirement for the makeup air provided to these exhausted spaces. This report therefore assumes that no outdoor air is required to be provided directly to the space. In reality, the air supplied directly to the space and the transfer air from adjacent spaces will provide for some outdoor air to the space. This should not have an effect on the calculations performed in this analysis.

Zone Discharge Airflow and Zone Primary Airflow

The zone discharge airflow, V_{dz}, is the expected supply airflow to the zone that includes primary supply air and all locally recirculated airflow. The zone primary airflow, V_{pz}, is the primary airflow supplied to the zone from the primary air supply and unit recirculated air only. V_{pz} does not include transfer air or air recirculated by other means.

For simplification, it is assumed that V_{dz} and V_{pz} are equal. This is a reasonable assumption since the only areas with transfer air are the restrooms, and they have no minimum outdoor air requirement in accordance with the previous assumption.

Occupant Density

Wherever possible, occupant densities are assigned to match those used to calculate the building egress requirements. Exceptions to this include gaming areas, where zone population has been based on fixed seating per architectural drawings, as well as restrooms where the fixture count is the basis for zone population.

In some areas, a higher occupant density than that listed in the egress drawings may be used. The airside concourse is an example of such a space. The egress drawings indicate an occupant density of 100 SF/person, whereas this report assumes an occupant density of 30 SF/person. This modification has been made based on the fact that the airside concourse may serve as an overflow area for gate holdrooms. As a result, it may be subject to larger zone populations. Finally, the calculations done in this report group some individual rooms into larger spaces based on function. This is mainly applicable to the concession areas since the floor area is reserved for later tenant assignment and fit out. Explanations of the occupant densities used for each space are included as notes for the calculations shown in Appendix A of this report.

Calculation Procedure

This section explains the Ventilation Rate Procedure, ASHRAE Standard 62.1-2007 Section 6.2, through a summary of required calculation steps. These calculations are representative of those used throughout the ventilation analysis performed in this report.

Classification of Spaces

The first step in the calculation process is to classify all of the spaces based on function. This is important because different types of spaces have different ventilation requirements. Zone areas and occupant densities are also determined at this time.

Breathing Zone Outdoor Air Flow, V_{bz}

The next step is to determine the breathing zone outdoor airflow through the use of ASHRAE Standard 62.1-2007 Equation 6-1.

$$V_{bz} = R_p \cdot P_z + R_a \cdot A_z$$

Where:

A_z = zone floor area
P_z = zone population
R_p = outdoor air flow rate required per person
R_a = outdoor air flow rate required per unit area

Zone Outdoor Air Flow, V_{oz}

Once the breathing zone outdoor air flow is known, the design zone outdoor air flow can be solved using ASHRAE Standard 62.1-2007 Equation 6-2.

$$V_{oz} = \frac{\mathrm{V_{bz}}}{\mathrm{E_z}}$$

Where:

V_{bz} = breathing zone outdoor air flow (found in the previous calculation)
E_z = zone air distribution effectiveness

For the existing systems, the assumption that $E_z = 1.0$ will result in V_{oz} being equal to V_{bz}. However, the redesigned system will analyzed with a value of E_z=1.2, indicating a higher zone air distribution effectiveness. Therefore, V_{oz} will be less than V_{bz} for the redesigned systems.

Outdoor Air Intake Flow, V_{ot}, for Single-Zone Systems

For single-zone systems, namely the airside concourse areas, the analysis is finished. For single zone systems, the outdoor air intake flow required is found by ASHRAE Standard 62.1-2007 Equation 6-3.

$$V_{ot} = V_{oz}$$

Where:

V_{oz} =zone outdoor air flow (found in the previous calculation)

Primary Outdoor Air Fraction, Z_p

For multi-zone VAV systems, further steps must be taken to determine the critical zone and account for overall system ventilation efficiency. The first step in this process is to determine Z_p by use of ASHRAE Standard 62.1-2007 Equation 6-5.

$$Z_p = \frac{\mathrm{V_{oz}}}{\mathrm{V_{pz}}}$$

Where:

V_{oz} = zone outdoor air flow (found earlier)
V_{pz} = zone primary airflow, or the minimum supply air quantity for the space

System Ventilation Efficiency, E_v

As stated in the assumptions, Appendix A of ASHRAE Standard 62.1-2007 is utilized in place of Table 6-3 for the calculation of all E_v values. Equation A-1 defines E_{vz} for single supply systems.

$$E_{vz} = 1 + \mathrm{X_s} - \mathrm{Z_d}$$

Where:

X_s = average outdoor air fraction

$$X_s = \frac{V_{ou}}{V_{ps}}, V_{ou} = \Sigma \mathrm{V_{bz}}, \text{ and } V_{ps} = \Sigma \mathrm{V_{pz}}$$

Z_d = discharge outdoor air fraction

$$Z_d = \frac{V_{oz}}{V_{dz}} \text{ and } V_{dz} = \mathrm{V_{pz}} \text{ (based on an assumptions)}$$

Once E_{vz} values have been found for all zones in the system, the overall system ventilation efficiency (E_v) can be defined as the minimum of these values.

Outdoor Air Intake Flow, V_{ot}, for Multi-Zone VAV Systems

For multi-zone systems, the analysis is finished. The outdoor air intake flow required is found by ASHRAE Standard 62.1-2007 Equation 6-8.

$$V_{ot} = \frac{V_{ou}}{\mathrm{E_v}}$$

Where:

V_{ou} = uncorrected outdoor air intake, $V_{ou} = \Sigma \mathrm{V_{bz}}$
E_v = system ventilation efficiency (found in previous calculation)

Discussion of Results

Appendix A of this report contains detailed calculations for the existing and redesigned air handling units in the area of focus. The results of these calculations are presented in Table 8 and Table 9. These tables list the required outdoor air flow (V_{ot}) for each air handling unit, as well as the system totals.

Since the air handling units have drastically different zoning arrangements, the comparison of the two systems is made based on the total outdoor air flow required for each alternative system type. As Table 8 and Table 8 indicate, the redesigned system that incorporates UFAD and displacement ventilation systems will have a lower outdoor air intake flow rate (V_{ot}). In fact, the redesigned system allows for a reduction of 52,677 CFM of outdoor air at the intake louver. Since the energy associated with conditioning this outside air can be quite large, there are obvious energy savings that result from these reduced outdoor air quantities.

Air Handling Unit No.	$V_{ot,}$ Outdoor Air Intake Flow Required [CFM]
AH-41	5,370
AH-43	17,755
AH-45	19,764
AH-47	9,850
AH-50a	3,386
AH-50b	2,356
AH-52	25,601
AH-54	17,257
AH-57	13,882
AH-59	6,019
AH-60	8,520
Existing System Total	**129,760**

Table 8: Summary of Outdoor Air Flow Rates for Existing Systems

Air Handling Unit No.	$V_{ot,}$ Outdoor Air Intake Flow Required [CFM]
AH-1R	1,699
AH-2R	2,963
AH-3R	4,417
AH-4R	3,061
AH-5R	3,702
AH-6R	2,522
AH-7R	3,121
AH-8R	1,995
AH-9R	2,411
AH-10R	1,397
AH-11R	3,344
AH-12R	2,018
AH-13R	2,425
AH-14R	3,601
AH-15R	2,495
AH-16R	8,432
AH-17R	8,380
AH-18R	8,061
AH-19R	3,606
AH-20R	7,435
Redesigned System Totals	**77,083**

Table 9: Summary of Outdoor Air Flow Rates for Redesigned Systems

Calculation of New Supply Air Quantities and Temperatures

Once the occupied zone loads and minimum outdoor air flow rates are determined for each room, the required supply air quantities can be calculated. The supply air and return air temperatures can also be determined at this time. All redesigned systems will seek to maintain the same indoor design conditions as the existing systems. These indoor design conditions are listed in Table 3 of the Calculation of Revised Space and System Loads section. Since the calculations for each type of system vary slightly, they will each be explained separately.

Calculation Procedure for Underfloor Air Distribution Systems

The first step in determining the necessary supply air flow rates is to establish the minimum acceptable supply air temperature. Since UFAD systems supply cool air at the floor level, the supply air temperature must be raised from the typical overhead supply air temperature of 55 °F. If air is supplied at too low of a temperature, an occupant in the space is likely to notice the temperature gradient between his or her ankles and head. In accordance with ASHRAE Standard 55, this temperature gradient must be maintained at less than 5 °F. Most resources indicate that 64 °F is the minimum advisable supply air temperature to maintain occupant satisfaction. Directly above the floor outlets, the air temperature then increases by 4-7 °F. The air temperature then continues to increase due to the loads in the occupied zone. It is this temperature difference that must be maintained at or below 5 °F to prevent dissatisfaction with the space. The air is then subject to an additional temperature increase due to loads in the unoccupied zone. The air temperature at this point will be equal to the return air temperature for the system.

All of the UFAD calculations performed for this analysis assume a supply air temperature of 65 °F. Once the supply air temperature is established, one can solve for the supply air flow rate required to meet the cooling load of the occupied zone.

$$\dot{V}_{Cool,UFAD}[CFM] = \frac{Q_{Total,Occupied\ Zone}\ [BTU/HR]}{(1.08) \times \left(T_{Setpoint}[°F] - T_{SA}[°F]\right)}$$

Where:

$Q_{Total,Occupied\ Zone}$ = total cooling load of the occupied zone
$T_{Setpoint}$ = indoor design temperature
T_{SA} = supply air temperature

At this point, this cooling load flow rate must be compared to the minimum outdoor air flow rate required for the space. The minimum outdoor air flow rates have been calculated in the previous section according to ASHRAE Standard 62.1-2007. The actual supply air flow rate to the zone is then the maximum of the cooling load flow rate ($V_{Cool,UFAD}$) and the required outdoor air flow rate (V_{oz}).

$$\dot{V}_{SA} = Maximum\{\dot{V}_{Cool,UFAD}, \dot{V}_{oz}\}$$

The final calculation involves the determination of the return air temperature due to the loads in both the occupied and unoccupied zones. This return air temperature is determined based on this total space load, the supply air temperature, and the supply air quantity.

$$T_{RA}[°F] = T_{SA}[°F] + \frac{Q_{Total}[BTU/HR]}{(1.08) \times (\dot{V}_{SA}[CFM])}$$

Where:

Q_{Total} = total space load for both occupied and unoccupied zones

Due to the large number of spaces included in the redesign, the calculations for each space are not included in this report. Instead, a sample calculation for Gate 01 Holdroom is included in Table 10. This sample calculation is provided to help demonstrate the calculation process used to determine the supply air quantities and air temperatures of each space.

UFAD Turbulent Mixing Design Calculations **Gate 01 Holdroom**			
Floor Area [SF]	3,759	Zone Outdoor Air Flow; V_{OZ} [CFM]	0
Design Room Set-Point; $T_{Setpoint}$ [°F]	75	Existing Supply Air Quantity; V_{SA} [CFM]	11,600
Traditional Mixing System Cooling Loads		*UFAD Mixing System Occupied Zone Cooling Loads*	
Lighting, Equipment; Q_{LE} [BTU/HR]	22,657	Lighting, Equipment; Q_{LE} [BTU/HR]	15,180
Envelope; Q_{EX} [BTU/HR]	82,488	Envelope; Q_{EX} [BTU/HR]	80,685
Conduction	7,840	Conduction	6,037
Solar	74,648	Solar	74,648
Occupants; Q_O [BTU/HR]	125,300	Occupants; Q_O [BTU/HR]	93,975
Total; Q_{Total} [BTU/HR]	230,445	Total; $Q_{Total, occupied zone}$ [BTU/HR]	189,840
Summer Cooling Flow Rate; V_{Cool} [CFM]		17,578	
Supply Air Flow Rate; V_{SA} [CFM]		17,578	
Supply Air Temperature; T_{SA} [°F]		65.0	
Return Air Temperature; T_{RA} [°F]		77.1	

Table 10: Sample Calculation for Gate 01 Holdroom Supply Air Flow Rate and Air Temperatures

A summary of the supply air quantities required by each space is included in Table 11. This table shows that the redesigned UFAD systems require larger supply air flow rates than the existing overhead mixing system. Research shows that these increased flow rates are a possibility with UFAD systems. At the same time, there are also some case studies that indicate supply air quantities for UFAD can be the same or lower than those for traditional systems. Ultimately, the difference in supply air flow rates will vary greatly based on the fraction of loads assigned to the occupied zone and the temperature difference of the supply air and design set point.

Room Name	Existing Supply Air Flow Rate [CFM]	UFAD Supply Air Flow Rate [CFM]	Difference [CFM]
Gate 01 / 02 Duty Free	60	139	79
Gate 01 / 02 Interview	70	227	157
Gate 01 / 02 Sterile Circulation	8,550	10,147	1,597
Gate 01 / 02 Wheelchair Storage	60	97	37
Gate 01 Holdroom	11,600	17,578	5,978
Gate 02 Holdroom	11,900	13,334	1,434
Gate 03 / 04 Duty Free	60	128	68
Gate 03 / 04 Interview	70	218	148
Gate 03 / 04 Sterile Circulation	6,700	8,156	1,456
Gate 03 / 04 Wheelchair Storage	60	50	-10
Gate 03 Holdroom	11,800	20,188	8,388
Gate 04 Holdroom	6,950	18,067	11,117
Gate 05 / 06 Duty Free	60	132	72
Gate 05 / 06 Interview	70	227	157
Gate 05 / 06 Sterile Circulation	8,460	10,125	1,665
Gate 05 Holdroom	5,000	7,595	2,595
Gate 05 Wheelchair Storage	60	51	-9
Gate 06 Electrical	160	257	97
Gate 06 Holdroom	5,800	17,525	11,725
Gate 07 Boarding Corridor	0	571	571
Gate 07 Electrical	160	224	64
Gate 07 Holdroom	6,320	9,186	2,866
Gate 08 / 09 Gaming	3,400	2,983	-417
Gate 08 Electrical	160	226	66
Gate 08 Holdroom	6,200	10,003	3,803
Gate 08 Wheelchair Storage	60	556	496
Gate 09 Holdroom	9,300	11,380	2,080
Gate 09 Telecomm	0	56	56
Gate 10 / 11 Gaming	3,400	2,993	-407
Gate 10 Electrical	160	199	39
Gate 10 Holdroom	11,540	14,684	3,144
Gate 11 Holdroom	8,240	15,571	7,331
Gate 12 Electrical	160	260	100
Gate 12 Holdroom	8,040	14,931	6,891
Gate 14 Electrical	160	199	39
Gate 14 Holdroom	13,500	14,534	1,034
Gate 15 Electrical	160	14,534	14,374
Gate 15 Holdroom	12,200	15,852	3,652
Total	**160,650**	**253,182**	**92,532**

Table 11: Comparison of Supply Air Quantities for Traditional and UFAD Systems

Calculation Procedure for Displacement Ventilation Systems

The calculation procedure for displacement ventilation systems is similar to UFAD systems, though careful attention must be given to the supply air temperature. Since the air being supplied to the occupied zone is not mixed like it is for an underfloor air distribution system, the potential for strong thermal gradients increases. In other words, occupants in the space may be more sensitive to supply air temperatures from a DV system than they would from an underfloor air distribution system.

Using the occupied zone loads calculated earlier, it is possible to solve for the supply air flow rate required to meet the cooling load of the occupied zone.

$$\dot{V}_{Cool,DV}[CFM] = \frac{Q_{Total,Occupied\ Zone}\ [BTU/HR]}{(1.08) \times \left(\Delta T_{hf}[°F]\right)}$$

Where:

T$_{hf}$ = temperature difference between head and foot

This equation is very similar to the one used to calculate supply air quantities for UFAD systems, except for the change in ΔT. In order to maintain occupant comfort in the space, ΔT_{hf} must be limited to 5 °F. A value of 3.6 °F is suggested for a space where occupants will be seated on an extended basis. However, since the airside concourse is more of a transient circulation area, ΔT_{hf} has been set to 5 °F. This low ΔT obviously creates a potential requirement for large quantities of supply air.

Once again, the cooling load flow rate must be compared to the minimum outdoor air flow rate. The maximum of these two values becomes the actual minimum supply air flow rate to the zone.

$$\dot{V}_{SA} = Maximum\{\dot{V}_{Cool,DV}, \dot{V}_{oz}\}$$

The supply air temperature is now calculated to determine an air temperature that will be acceptable to the occupants.

$$T_{SA}[°F] = T_{Setpoint}[°F] - T_{hf}[°F] - \frac{A[SF] \times Q_{Total}\ [BTU/HR]}{(2.33) \times ((V_{SA}[CFM])^2) + (1.08) \times (A[SF]) \times (V_{SA}[CFM])}$$

Where:

A = floor area of the space

The return air temperature is now calculated in the same manner as it was for the UFAD system. Again the total load for both the occupied and unoccupied zones is used.

$$T_{RA}[°F] = T_{SA}[°F] + \frac{Q_{Total}[BTU/HR]}{(1.08) \times \left(\dot{V}_{SA}[CFM]\right)}$$

Similar to the underfloor air distribution calculations, a sample of the displacement ventilation calculations is included in place of the calculations for all spaces. This sample calculation is for Gate 01 Airside Concourse, and is included in Table 12. Although this table looks similar to the one used for the UFAD calculations, the values are obtained in different ways as indicated previously.

A summary of the supply air quantities required fore each space is also included in Table 13. This table shows that the redesigned displacement ventilation systems also require larger supply air flow rates than the existing overhead mixing system. It is important to note the increase in these airflows despite the reduction in load applied to the occupied zone. These increases in air quantities are likely a result of the small ΔT_{hf} required to maintain occupant comfort.

Displacement Ventilation Design Calculations **Gate 01 Airside Concourse**			
Floor Area [SF]	9,600	Zone Outdoor Air Flow; V_{OZ} [CFM]	0
Design Room Set-Point; $T_{Setpoint}$ [°F]	75	Existing Supply Air Quantity; V_{SA} [CFM]	11,250
Traditional Mixing System Cooling Loads		*UFAD Mixing System Occupied Zone Cooling Loads*	
Lighting; Q_L [BTU/HR]	49,147	Lighting; Q_L [BTU/HR]	6,487
Envelope; Q_{EX} [BTU/HR]	157,133	Envelope; Q_{EX} [BTU/HR]	29,070
Conduction	16,007	Conduction	2,961
Solar	141,126	Solar	26,108
Occupants, Equipment; Q_{OE} [BTU/HR]	192,382	Occupants, Equipment; Q_{OE} [BTU/HR]	56,753
Total; Q_{Total} [BTU/HR]	398,662	Total; $Q_{Total,\ Occupied\ Zone}$ [BTU/HR]	92,310
Summer Cooling Flow Rate; V_{Cool} [CFM]		17,094	
Supply Air Flow Rate; V_{SA} [CFM]		17,094	
Supply Air Temperature; T_{SA} [°F]		65.5	
Return Air Temperature; T_{RA} [°F]		87.1	

Table 12: Sample Calculation for Gate 01 Airside Concourse Supply Air Flow Rate and Air Temperatures

Room Name	Existing Supply Air Flow Rate [CFM]	DV Supply Air Flow Rate [CFM]	Difference [CFM]
Gate 01 Airside Concourse	11,250	17,094	5,844
Gate 02 Airside Concourse	11,250	13,906	2,656
Gate 03 Airside Concourse	11,250	12,842	1,592
Gate 04 / 05 Airside Concourse	20,945	26,611	5,666
Gate 06 / 07 Airside Concourse	13,500	13,769	269
Gate 08 Airside Concourse	5,625	6,217	592
Gate 09 / 10 Airside Concourse	23,195	28,411	5,216
Gate 11 / 12 Airside Concourse	22,070	26,825	4,755
Gate 14 / 15 Airside Concourse	11,250	16,822	5,572
Total	**130,335**	**162,497**	**32,162**

Table 13: Comparison of Supply Air Quantities for Traditional and DV Systems

Load Calculation Conclusions

As shown in Table 11 and Table 13, both of the redesigned system types will require increases in supply air flow rates. When the results of the UFAD and DV calculations are combined, it becomes apparent that an additional 124,694 CFM will be required in the area of redesign. This drastic increase creates some initial concerns about the additional energy consumption associated with the increase. However, energy consumption can not be analyzed without taking into account other aspects which could actually reduce the consumption rate. Therefore, this analysis will be discussed in greater detail later in this report.

New System Zoning and Air Handling Units

Explanation of New Zoning for Area of Redesign

As noted earlier, the redesigned systems will have supply air temperatures that are higher than those of traditional overhead mixing systems. Looking at the sample calculations performed in the previous section, the supply air temperatures will be approximately 65 °F for both the UFAD and DV systems. However, the supply air temperature for most of the other spaces within Terminal 3 is approximately 55 °F. The problem with these differing temperatures is that some of the units currently serving the area of redesign also serve areas that are not included in the redesign. As a result, supply air would have to be reheated prior to being used in the UFAD or DV systems. This idea, combined with a need for larger amounts of supply air, makes it a good idea to re-zone the air handling units. In doing so, additional capacity can be added to properly meet the load of the spaces. At the same time, the separation of the various system types ensures that the air is conditioned to the proper temperature without the need for reheat.

Since the air flow rates for each space have already been calculated, this analysis can be used to group certain spaces together. The main concern with the zone selections is maintaining separation between underfloor air distribution, displacement ventilation, and traditional overhead systems. Other concerns include maintaining reasonable sizes for air handling units, and ensuring that the air handlers are reasonably close to the spaces they will be serving.

Zone Assignments and Location of New Air Handling Equipment

When determining the zoning assignments for the new air handling equipment, it is also important to consider where the air handling units themselves will be located. The existing units that serve the current overhead mixing system in this area are located either in second floor mechanical rooms, or in the mechanical penthouses on the level above. That being said, the space occupied by the current units should be used wherever possible. In order to achieve this, the spaces that will continue to be served by overhead mixing systems must first be grouped together. As mentioned before, many of these units serve limited areas that will continue to have overhead distribution systems. Some of these air handlers must be maintained to continue to serve these spaces; however, many of the units can be grouped together to free up floor area for the new units.

Once the traditional overhead systems have been assigned, the redesigned UFAD and DV systems can be zoned and assigned to various air handling units. This is a somewhat iterative process that begins by assigning adjacent spaces to a given air handling unit. From here, spaces are shifted and split between various systems until all of the units have a reasonable size and area of service. At the same time, it must be verified that these air handling units are capable of fitting within the existing mechanical room space.

As indicated earlier in this report, the redesigned systems will require supply air quantities greater than those of the existing system. In order to provide this additional capacity, the number of air handling units must be increased. To accommodate these extra units, additional floor space must be assigned to mechanical rooms. Since every effort is made to avoid disrupting the existing architecture of the space, innovative solutions to this problem must be considered. The proposed solution to this problem is to locate some of the additional units above the egress stairs on the south side of the building. These stair towers are spaced periodically throughout the length of the building and extend to the same roof height as the adjacent holdrooms and airside concourse. As indicated earlier, these are spaces that are large in height. That being said, elevated mechanical rooms could feasibly be included in the egress stairs at a height of approximately 8'-0" above the floor of Level 2. Figure 8 shows a section through a typical egress stair tower.

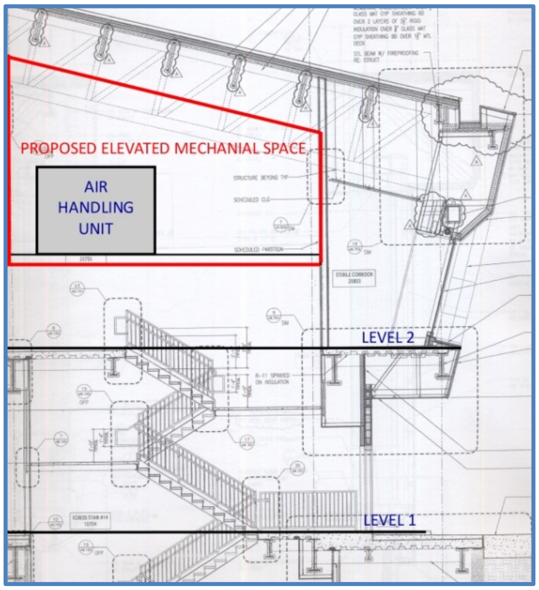

Figure 8: Section Through Egress Stairs

Since these stairways are used for emergency egress only, there should not be any architectural concerns with modifying the stair towers. Furthermore, it should not be difficult to create wall assemblies that ensure sound transmission into adjacent spaces is not an issue. Figure 9 highlights the relative size and location of these stairs in relation to the numbered gates. Referring back to Figure 7 earlier in this report, one can also see a typical stair tower in the distance just beyond the gate holdroom.

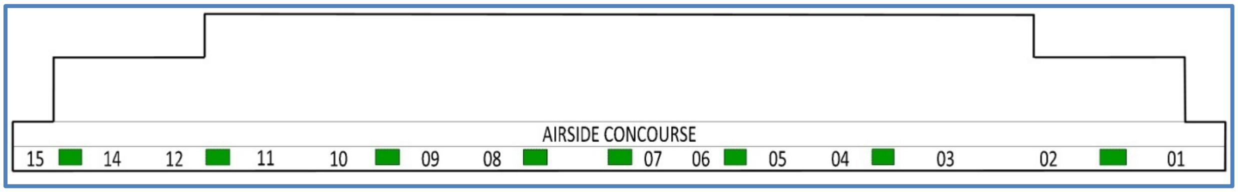

Figure 9: Location of Egress Stairs

Obviously, there is a limit to the size of the air handling units that could be included within the egress stairs. A typical egress stair measures approximately 45'-6" x 29'-0". Taking into account equipment clearances and sizes of existing units, it is still reasonable to assume that a unit size of up to about 25,000 CFM could be included in such a space. In order to maintain this maximum size, only those air handling units serving the airside concourse will be located within the egress stairs. Since the airside concourse typically has lower supply air flow rates than the adjacent holdroom areas, the units serving them should be the appropriate size for the existing floor area and location of the egress stairs.

Once again, the architectural impacts of these elevated mechanical rooms should not be an issue. This solution does not require that the roof height of the stair towers be altered, and they should continue to fit in smoothly with the existing roof height and slope. This modification can also likely be made with minimal increase in construction cost. The stair enclosures have masonry enclosures, and therefore sound transmission through these walls should be minimal. The only real increase in cost arises from the need to provide structural support for the proposed mezzanine slab. Since the spaces are small in size, this is still a feasible cost. One main design goal of the architect was to avoid having louvers within clear sight on any building façade. In order to achieve this, the louvers are restricted to the low roof area running along the center of the long building dimension. This low roof area is located approximately 50’-0” from the egress stairs, and has plenty of wall area for both outdoor air and relief air louvers. Furthermore, this area is open to configurations that ensure minimum separation between exhaust air and outdoor air louvers can be maintained in accordance with ASHRAE Standard 62.1-2007.

Table 14 provides a summary of the new air handling units, including sizes and locations. Tables with more detailed explanations of these units can be found in Appendix B of this report. These tables summarize the air handling units that will serve the redesigned UFAD and DV systems, as well as which existing units have been combined to serve the remaining overhead mixing systems in the area.

Air Handling Unit No.	Location	System Type Served	SA Flow Rate [CFM]
AH-1R	Current location of AH-60	UFAD	30,000
AH-2R	Above egress stairs #21 and #22	DV	25,000
AH-3R	Current location of AH-57	UFAD	45,000
AH-4R	Above egress stairs #19 and #20	DV	25,000
AH-5R	Available penthouse space	UFAD	40,000
AH-6R	Above egress stairs #14 and #15	DV	25,000
AH-7R	Current location of AH-52	UFAD	30,000
AH-8R	Above egress stairs #12 and #13	DV	15,000
AH-9R	Current location of AH-47	UFAD	15,000
AH-10R	Above egress stairs #10 and #11	DV	15,000
AH-11R	Current location of AH-43	UFAD	35,000
AH-12R	Above egress stairs #08 and #09	DV	20,000
AH-13R	Above egress stairs #06 and #07	DV	25,000
AH-14R	Current location of AH-41	UFAD	45,000
AH-15R	Above egress stairs #04 and #05	DV	20,000
AH-16R	Current location of AH-45	Overhead	20,000
AH-17R	Current location of AH-50a	Overhead	35,000
AH-18R	Current location of AH-50b	Overhead	40,000
AH-19R	Current location of AH-54	Overhead	20,000
AH-20R	Current location of AH-59	Overhead	30,000
		Redesigned System Total	**555,000**

Table 14: Summary of Redesigned Air Handling Units

System Components and Proposed Layout

This section is included to provide a basic understanding of the equipment that is necessary to serve typical spaces throughout Terminal 3. The approach of selecting equipment for a typical space is used since the systems in each space tend to be similar, and the building area is quite large to analyze this section in detail. Figure 10 provides a plan view of the spaces selected for the typical layouts. Note that only a portion of each holdroom is shown in this figure. These spaces actually extend far beyond the scope of this plan.

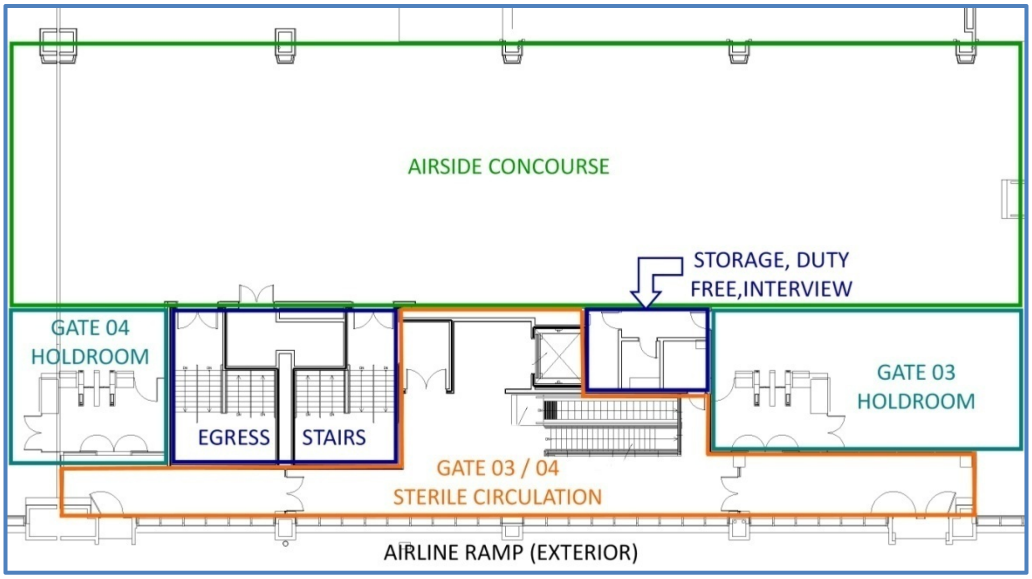

Figure 10: Plan of Rooms Included in Typical Design Area

For the purpose of this analysis, equipment selections have been made using Price products as the basis of design. There are obviously many suppliers of both UFAD and DV equipment, and comparable systems could likely be created using another manufacturer as the basis for design. It is also important to note that the return air portion of the overhead mixing system is considered existing to remain and will be used as is for the redesigned systems.

Underfloor Air Distribution Equipment Selections and Typical Layout

The redesigned UFAD system requires equipment that can be substantially different from that used in an overhead mixing system. The rooms used to describe typical UFAD systems in Terminal 3 are Gate 02 Holdroom, Gate 03 Holdroom, Gate 03 / 04 Sterile Corridor, Gate 03 / 04 Duty Free, Gate 03 / 04 Storage, and Gate 03 / 04 Interview. These rooms comprise the spaces served by AH-3R. Similar groupings of these same space types are served by other air handling units and similar UFAD equipment.

Since the gate holdrooms and sterile corridors are all perimeter spaces, the first step is to calculate the number of diffusers required along the perimeter wall. It is important to consider that this perimeter area will likely require heating in the winter season. At the same time, the diffusers in this area must also be capable of dealing with a high solar load during the summer months. In order to effectively meet both of these criteria, linear floor grilles are selected for these areas. The LFG-H model by Price is capable of providing both VAV cooling and constant volume heating, and is shown in Figure 11. When operating in cooling mode, the unit damper modulates to draw air from the supply air plenum. When perimeter heating is required, this damper is modulated to receive air from a ducted supply. This ducted supply is connected to a fan powered terminal unit that is capable of providing warm air to the perimeter while the supply air plenum provides cool air to the interior zone.

Figure 11: Linear Floor Grille for UFAD (Courtesy Price HVAC)

Based on the supply air flow rate calculations; 8,156 CFM is required to meet the cooling loads of the Gate 03 / 04 Sterile Corridor. Looking at performance data for the selected model, 16" x 8" linear floor grilles can be selected to provide 300 CFM each. Since this space remains in close proximity to the south exterior wall, it is reasonable to provide all of the space conditioning through these linear floor grilles. Based on the total supply air required in the space, 28 linear floor grilles will be required in this space. As mentioned earlier, these diffusers will be served by fan powered terminal units. The FDBU-5000 model is selected to serve the floor grilles. Each terminal unit is capable of supplying up to 1,950 CFM. Based on this maximum value, five terminal units will be required to serve the sterile corridor. A special controller is also required for this equipment. The UMCB controller is capable of controlling the dampers on each floor grille, as well as the terminal units. Based on a limited number of outputs per controller, a total of three controllers will be required to serve this zone. Despite this, these controllers can be wired together to ensure consistent control throughout the space.

The perimeter zone for each of the gate holdrooms is designed in a similar manner. The total supply air flow rate for Gate 02 Holdroom and Gate 03 Holdroom combined is 33,522 CFM. The same linear floor grilles will be used in this space to provide a total of 18,000 CFM of cool air along the perimeter. Based on the maximum 300 CFM capacity of each floor grille, a total of 60 grilles will be required in the holdroom areas. Similar to the calculation for Gate 03 / 04 Sterile Corridor, ten FDBU-5000 Terminal units and six UMCB controllers are required to serve these linear floor grilles.

The gate holdrooms will also have an interior zone served by round floor diffusers. The remaining combined supply air flow rate required for Gate 02 Holdroom and Gate 03 Holdroom is 15,522 CFM. This remaining flow rate will be served by round floor inclined flow diffusers. These RFID diffusers use a combination of radial and circular discharge jets to supply cool air to the space, and can be seen in Figure 12. These diffusers are selected because the mixing pattern they create allows for occupants to be closer to the diffuser before experiencing discomfort from drafts.

Figure 12: RFID Round Diffuser and DB Basket (Courtesy Price HVAC)

Based on performance data about air throws and capacities, 8” RFID diffusers will be selected to provide 100 CFM each. The interior zone of these gate holdrooms will therefore require 155 of these diffusers. A distributor basket will be included with each diffuser. These baskets are provided to ensure even distribution of supply air through the diffuser. At the same time, these baskets catch any debris that falls through the diffuser face. This helps to avoid debris and other contaminants from entering the plenum space itself. Furthermore, these baskets have manual dampers that allow for volume adjustment by operations staff. These dampers are not required for balancing because the pressurized plenum serving these diffusers should be self-balancing. VAV control of these diffusers is provided through the use of another set of terminal units. The pressurized plenum serving the round diffusers will require an additional eight terminal units. As a reminder, these terminal units will be capable of providing cool air to the interior zone while warm air is provided to the perimeter zone. Likewise, all terminal units can be used to provide either cool or warm air throughout the space.

The final rooms included in this typical design are the Gate 03 / 04 Duty Free, Gate 03 / 04 Storage, and Gate 03 / 04 Interview rooms. Since these spaces consist only of interior zones, the same round floor diffusers mentioned before will be used. Two diffusers will be used in each room to provide the appropriate amount of supply air to each space with an even throw pattern. All of these diffusers can be served by one terminal unit, similar to the existing overhead system. This underfloor terminal unit works like the ones mentioned earlier, though it will be sized to a smaller maximum capacity of 850 CFM. A single UMCB controller will be used to control the terminal unit serving these rooms.

Like the existing overhead distribution equipment, this underfloor air distribution equipment allows the system to work on a VAV basis. This control strategy is important since many of these spaces are subject to frequent fluctuations in loads. The system components prescribed for these typical spaces should be capable of meeting these changing loads effectively and quickly. At the same time, they are designed to be easy to maintain and operate. Cost analysis of these components will be included in a later section of this report. This section will take into account other costs associated with the redesigned system to assist in establishing comparison criteria for the various systems.

Displacement Ventilation Equipment Selections and Typical Layout

The only real equipment modification required to transform an overhead mixing system into a displacement ventilation system is the replacement of the diffusers. Once again, the amount of equipment required for such a system is demonstrated through the design of a typical space. The space included in this typical design will be the airside concourse that extends from the western portion of Gate 02 to the eastern portion of Gate 04. These spaces are all served by AH-4R. The airside concourse is about 48’-0” in width throughout Terminal 3. The length dimension of this particular portion is approximately 335’-0”. A total of 21,845 CFM of supply air is required to serve the cooling load of the occupied zone.

Due to the limited amount of wall space in this area of the building, diffuser throws become a crucial criterion for the selection of equipment. A review of the displacement diffusers offered by Price indicates that rectangular 1-way displacement diffusers, DF1 Series, offer the best coverage areas per diffuser. This model is also capable of distributing large volumes of air effectively, while maintaining low noise criteria of NC-21. Unfortunately, the coverage range of these diffusers is still not enough to cover the areas between current wall segments. The architecture of the space only has small segments of wall that function as column enclosures. These enclosures are about 3’-0” in width, and are spaced approximately 40’-0” on center. Based on the spacing of these existing walls and diffuser coverage about 20 feet in width, a large area of space between the wall segments will not receive coverage. This is a serious problem, as every effort is made to avoid altering the space architecturally.

It is apparent that the diffusers will have to be spaced closer together than the existing wall segments will allow. In order to achieve this, a number of innovative solutions could be incorporated into the design. Research indicates that there a number of creative ways to incorporate displacement diffusers into a space. These diffusers can be included in items such as large planters and furniture within the space. At the same time, false columns can be used as installation space for displacement diffusers. With regards to Terminal 3, it would be suggested that partial height wall segments be included along the edges of the airside concourse. These wall segments would be of similar size to the existing wall segments, and could be clad in material that would be architecturally pleasing. The diffusers located in these interstitial wall segments could be supplied by ductwork connecting to either the top or bottom of the diffusers. If bottom connections are used, the new wall segments would not even have to extend the full height of the concourse. At the same time, a number of slab penetrations would have to be made, so the point of connection must be carefully considered. Either way, it is likely that the necessary diffuser spacing can be achieved with minimal alteration of the architecture. The DF1 displacement diffuser is shown if Figure 13 as well as duct covers that can be used to conceal ductwork serving top connection diffusers.

Figure 13: DF1 Displacement Diffuser and Duct Cover (Courtesy Price HVAC)

Based on a diffuser spacing of 20’-0”, the typical space used in this analysis will require 36 DF1 diffusers. Given the total supply air flow rate required by this space, it can be seen that each individual diffuser will have a flow rate of about 605 CFM. These diffusers will measure 36”w x 60”h x 16”d, and have a rectangular duct connection size of 18” x 8”. It is also important to note that these diffusers have a throw of about 20 feet into the space as well. That being said, the diffusers will be required on either side of the airside concourse running in the direction of the long dimension.

As far as terminal units are concerned, the VAV boxes that currently serve the overhead mixing system can continue to be used. The only change is that the increased supply air flow rates will require additional terminal units. Based on continued use of VAV boxes with a capacity of 2,250 CFM; the redesigned system will only require two additional terminal units. Like the UFAD system, the cost impacts of the system described here will be evaluated in the next section of this report.

Energy Consumption and Cost Analysis

In order to make accurate comparisons about the various systems, energy consumption and cost analysis must be taken into account. After all, one of the main goals of the redesigned system was to reduce operating costs through minimization of energy consumption. In order to determine if this was achieved, the changes in operation must be closely evaluated and simulated whenever possible. At the same time, initial system costs must also be taken into account. Even if they redesigned system is capable of reducing annual costs, it must have an affordable construction cost and small payback period.

Differences in Initial Equipment Costs

In the previous section of this report, typical equipment selections and designs layouts were made for both UFAD and DV systems. Since cost analysis was not taken into account before, it is discussed here. Again, the pricing calculations performed for these typical spaces should be representative of costs for other rooms served by the new systems. The intention of this cost analysis is to determine a cost per square foot difference between the redesigned systems and the existing systems.

The pricing calculations begin with the typical underfloor air distribution system mentioned earlier. Using general budget prices, an approximate cost can be determined for the UFAD system components. The addition of this equipment will also lead to the removal of some of the equipment used in the overhead distribution system. Prices for the removed equipment are taken from the actual cost estimate performed for the building. Table 15 shows a list of the additional equipment, as well as the removed equipment for the typical UFAD zone designed earlier.

Table 15 also shows a final cost difference between the two systems for the typical space. This cost is then translated into a corresponding cost per square foot. Using this cost per square foot, the typical cost difference between the two systems can be applied to the entire area of study. This is used to determine a final cost difference between the underfloor air distribution system and the existing overhead mixing system. Using a similar procedure, a cost analysis can also be performed for the DV system designed for the typical airside concourse space. This cost summary is shown in Table 16.

The cost analysis for the air handling units serving the redesigned systems is performed separately. As indicated earlier, the redesigned systems require higher supply air flow rates. These increased air flow rates require an additional nine air handling units compared to the existing system. This significant increase in the number of air handling units has an obvious cost increase associated with it. Table 17 shows the breakdown for the costs of both the existing and redesigned air handling units. Cost data for the existing air handling units is taken from the actual cost estimate performed for Terminal 3. Using these numbers, estimates for the redesigned air handling units can also be made based on pricing for units of the same size. As Table 17 indicates, the additional air handling units will cost approximately $716,420. If all of the equipment costs are combined together, the redesigned systems will require an increase of about $1,056,285 in initial investment. This is a substantial cost difference, but it is important to recall that the cost of the existing mechanical system is $61,994,928 for the equipment in the terminal itself; and $18,658,073 for the equipment contained in the central plant serving Terminal 3. Therefore, the cost increase of the redesigned system is only 1.3% of the existing system cost.

Air Handling Unit Tag: AH-3R				
Item Description	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
03 / 04 Sterile Corridor				
Linear Grilles 16" x 8" (Price: LFG-HC / 16A / B17)	28	Each	$335.00	$9,380.00
Terminal Units (Price: FDBU 5000 / Unit Size 50)	5	Each	$1,302.00	$6,510.00
Slot Diffuser	134	LF	-$50.00	-$6,700.00
Terminal Units	2	Each	-$1,000.00	-$2,000.00
Volume Dampers (10" Diam)	23	Each	-$46.50	-$1,069.50
			Sub-Total	**$6,120.50**
03 / 04 Duty Free, 03 04 Interview, 03 / 04 Storage				
8" Round Floor Inclined Diffusers (Price: RFID / 8 / DB)	6	Each	$110.00	$660.00
Terminal Units (Price: FDBU 5000 / Unit Size 20)	1	Each	$679.00	$679.00
Square Diffusers (12 / 12, 6" Neck, 125 CFM)	3	Each	-$200.00	-$600.00
Terminal Units	1	Each	-$750.00	-$750.00
			Sub-Total	**-$11.00**
02 / 03 Holdroom				
Linear Grilles 16" x 8" (Price: LFG-HC / 16A / B17)	60	Each	$335.00	$20,100.00
8" Round Floor Inclined Diffusers (Price: RFID / 8 / DB)	155	Each	$110.00	$17,050.00
Terminal Units (Price: FDBU 5000 / Unit Size 50)	18	Each	$1,302.00	$23,436.00
Slot Diffuser	544	LF	-$50.00	-$27,200.00
Terminal Units	15	Each	-$1,000.00	-$15,000.00
Volume Dampers (10" Diam)	102	Each	-$46.50	-$4,743.00
			Sub-Total	**$13,643.00**
Total				**$19,752.50**
Total Per Square Foot	**13,144**	**SF**		**$1.50**
Typical Cost Translated to Total Floor Area for UFAD	**69,451**	**SF**		**$104,369.36**

Table 15: Cost Comparison for UFAD and Traditional Overhead Systems

Air Handling Unit Tag: AH-4R				
Item Description	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
02 (West) / 03 / 04 (East) Airside Concourse				
Displacement Diffusers 30" x 60" x 16" (Price: DF1 / 18 x 8)	36	Each	$1,105.00	$39,780.00
Additional Terminal Units	2	Each	$1,000.00	$2,000.00
Jet Diffuser	26	Each	-$200.00	-$5,200.00
Total				**$36,580.00**
Total Per Square Foot	**15,997**	**SF**		**$2.29**
Typical Cost Translated to Total Floor Area for DV	**100,800**	**SF**		**$230,497.22**

Table 16: Cost Comparison for DV and Traditional Overhead Systems

Air Handling Unit No.	**Service**	**Size [CFM]**	**Estimated Cost**
Existing Air Handling Units			
AH-41	Gate 14 / 15 Holdrooms and Airside Concourse	30,000	$135,200.00
AH-43	Gate 11 / 12 Holdrooms and Airside Concourse	45,000	$218,400.00
AH-45	Gate 10 Holdroom and Airside Concourse	50,000	$221,000.00
AH-47	Gate 08 / 09 Holdrooms and Airside Concourse	50,000	$221,000.00
AH-50a	TSA Waiting West and Airside Concourse	30,000	$135,200.00
AH-50b	TSA Waiting East and Airside Concourse	30,000	$135,200.00
AH-52	Gate 06 / 07 Holdrooms and Airside Concourse	55,000	$237,380.00
AH-54	Gate 04 / 05 Holdrooms and Airside Concourse	50,000	$221,000.00
AH-57	Gate 03 Holdroom and Airside Concourse	40,000	$166,400.00
AH-59	Gate 02 Holdroom and Airside Concourse	40,000	$166,400.00
AH-60	Gate 01 Holdroom and Airside Concourse	40,000	$166,400.00
	Total Cost for Existing Air Handling Units	**460,000**	**$2,023,580.00**
New Air Handling Units			
AH-1R	Gate 01 Holdroom	30,000	$135,200.00
AH-2R	Gate 01 / 02 Airside Concourse	25,000	$124,800.00
AH-3R	Gate 02 / 03 Holdrooms	45,000	$218,400.00
AH-4R	Gate 02 (West) / 03 / 04 (East) Airside Concourse	25,000	$124,800.00
AH-5R	Gate 04 / 05 Holdroom	40,000	$166,400.00
AH-6R	Gate 04 (West) / 05 Holdroom	25,000	$124,800.00
AH-7R	Gate 06 / 07 Holdroom	30,000	$135,200.00
AH-8R	Gate 06 / 07 Airside Concourse	15,000	$93,600.00
AH-9R	Gate 08 / 09 Holdroom	25,000	$124,800.00
AH-10R	Gate 08 / 09 (East) Airside Concourse	15,000	$93,600.00
AH-11R	Gate 10 / 11 Holdroom	35,000	$150,000.00
AH-12R	Gate 09 (West) / 10 Airside Concourse	20,000	$120,000.00
AH-13R	Gate 11 / 12 (East) Airside Concourse	25,000	$124,800.00
AH-14R	Gate 12 / 14 / 15 Holdroom	45,000	$218,400.00
AH-15R	Gate 12 (West) / 14 / 15 Airside Concourse	20,000	$120,000.00
AH-16R	OH Loads Currently Served by AH-43 and AH-45	15,000	$93,600.00
AH-17R	OH Loads Currently Served by AH-47 and AH-50a	35,000	$150,000.00
AH-18R	OH Currently Served by AH-50b and AH-52	40,000	$166,400.00
AH-19R	OH Loads Currently Served by AH-54	20,000	$120,000.00
AH-20R	OH Loads Currently Served by AH-57, AH-59, AH-60	30,000	$135,200.00
	Total Cost for New Air Handling Units	**560,000**	**$2,740,000.00**
Total Cost Difference			**$716,420.00**
Total Cost Difference Per Square Foot		**170,251 SF**	**$4.21**

Table 17: Cost Comparison for Existing and New Air Handling Units

Energy Savings Associated with Increased Economizer Operation

As mentioned before, both UFAD and DV systems have a potential for increased economizer operation. This is due to the fact that the supply and return air temperatures for both systems are higher than those temperatures used for the existing system. The Sequence of Operation for the existing system indicates that airside economizer operation is enabled when the outside air temperature is less than the return air temperature. This means that the economizer is enabled whenever the outside air temperature is less than 75 °F. In contrast, the underfloor air distribution and displacement ventilation systems have return air temperatures that are more like 80 °F and 85 °F respectively. This means that the air handling units serving these systems can operate in economizer mode for an additional 5 – 10 °F range of outdoor air temperatures.

In order to determine the energy saving associated with this increased range, a bin analysis is performed on the economizer operation. Since most of the redesigned system economizer will overlap with the existing system economizer, the analysis is only required for the additional temperature range. The first step in the calculation process is to find the annual bin weather data. Based on this weather data, it becomes apparent that the bins of interest will be in the dry bulb range of 75 – 79 °F and 80 – 84 °F. From here, psychrometric calculations can be used to determine the enthalpy associated with these bins. This enthalpy is found using the average dry bulb temperature and mean coincident wet bulb temperature of each bin. The indoor enthalpy condition must also be determined at this time. This value is found using the indoor design conditions of 75 °F and <50% RH. Knowing these enthalpies, as well as the supply air quantities for each system type, the energy savings per hour can be found for each bin.

$$q_{bin}[BTU/hr] = (4.5) \times (V_{SA}[CFM]) \times (h_{bin} - h_{indoor}\ [BTU/lbm])$$

Once this value is found for each bin, the annual energy savings can be found. This step involves simply multiplying the energy savings per hour by the number of annual hours in the respective bin.

$$q_{bin}[BTU/yr] = (q_{bin}\ [BTU/hr]) \times (t_{bin}[hr])$$

The resultant sum of the various bins will yield the total annual energy savings that are possible for each of the redesigned systems on an annual basis. Table 18 and Table 19 show these calculations for each of the redesigned system types. As the analysis shows, the energy saving can be significant and may help to offset the high initial cost of the equipment required.

Economizer Savings for Underfloor Air Distribution Systems	
Supply Air Quantity; V_{SA} [CFM]	238,825
Design Room Set-Point; T_{SP} [°F]	75
Return Air Temperature; T_{RA} [°F]	80
Indoor Design Enthalpy (75 °F DB, <50% RH) [BTU/lbm]	28.1
Hourly Energy Savings	
Outdoor Air 75-79 °F Bin	
Enthalpy (T_{BinAvg} DB, 55 °F MCWB); h_{77} [BTU/lbm]	23.9
Energy Savings per Hour; q_{77} [BTU/hr]	4,513,793
Annual Energy Savings	
Outdoor Air 75-79 °F Bin	
Total Bin Hours; $t_{75\text{-}79}$	606
Annual Energy Savings; q_{77} [BTU/yr]	2,735,358,255
Total Annual Energy Savings; q_{Econ} [BTU/yr]	**2,735,358,255**
Floor Area Served by UFAD Systems [SF]	**69,451**
Total Annual Energy Savings per Square Foot [BTU/SF]	**39,385.4**

Table 18: Economizer Energy Savings for UFAD Systems

Economizer Savings Displacement Ventilation Systems	
Supply Air Quantity; V_{SA} [CFM]	162,500
Design Room Set-Point; T_{SP} [°F]	75
Return Air Temperature; T_{RA} [°F]	85
Indoor Design Enthalpy (75 °F DB, <50% RH) [BTU/lbm]	28.1
Hourly Energy Savings	
Outdoor Air 75-79 °F Bin	
Enthalpy (T_{BinAvg} DB, 55 °F MCWB); h_{77} [BTU/lbm]	23.9
Energy Savings per Hour; q_{77} [BTU/hr]	3,071,250
Outdoor Air 80-84 °F Bin	
Enthalpy (T_{BinAvg} DB, 58.3 °F MCWB); h_{82} [BTU/lbm]	26.1
Energy Savings per Hour; q_{82} [BTU/hr]	1,462,500
Annual Energy Savings	
Outdoor Air 75-79 °F Bin	
Total Bin Hours; $t_{75\text{-}79}$	606
Annual Energy Savings; q_{77} [BTU/yr]	1,861,177,500
Outdoor Air 80-84 °F Bin	
Total Bin Hours; $t_{80\text{-}84}$	771
Annual Energy Savings; q_{82} [BTU/yr]	1,127,587,500
Total Annual Energy Savings; q_{Econ} [BTU/yr]	**2,988,765,000**
Floor Area Served by Displacement Systems [SF]	**100,800**
Total Annual Energy Savings per Square Foot [BTU/SF]	**29,650.4**

Table 19: Economizer Energy Savings for DV Systems

Comparison of Annual Energy Consumption

The final analysis required to make overall cost comparisons is an evaluation of the annual energy consumption for both the existing and redesigned systems. In order to perform this task, Trane TRACE software is once again used. As mentioned previously, this software will provide for a full simulation of annual system operation. This simulation is considered to be the most feasible approach for taking into account the combined differences in outdoor air flow rates, supply air flow rates, economizer operation, and other factors.

Since all of the spaces have already been modeled to determine the load calculations performed earlier, this analysis is relatively simple. Using the existing model, two alternatives are created in TRACE. One of these alternatives will be the existing overhead mixing system, and the other will be the redesigned UFAD and DV systems. From here, changes can be made to each alternative in order to create as accurate of a model as possible. It is important to note that the simulations are set up to provide information relative to maximum cooling load. In other words, the simulation does not take into account time of use schedules for occupancy and equipment. These schedules have not been included because the occupancy for an airport facility is subject to many fluctuations. As a result, time of use schedules could not accurately be created without an in depth study of the actual facility. Despite this, the lack of these schedules should not impact the analysis. While the absolute energy consumption of each alternative will be overestimated, they will both be overestimated to the same extent. In other words, since this analysis is only interested in the cost differences between the two systems, the load profiles will not matter.

Other factors consistent between the two systems are also entered at this time. This includes the design indoor and outdoor conditions mentioned during the load calculations, as well as the rates for the various utilities. The design conditions are included in Table 2 and Table 3, both presented earlier in this report. The utility rates for both natural gas and electric are shown in Table 20.

Natural Gas (Southwest Gas Schedule SG-5L)			
Period	**Service Charge per Month**	**Consumption Charge per Therm**	**Demand Charge per kW**
All Periods	$150.00	$1.03450	$0.00
Electric (Nevada Power Schedule LGS-3)			
Period	**Service Charge per Month**	**Consumption Charge per kW**	**Demand Charge per kW**
Summer On-Peak	$254.60	$0.10758	$9.17
Summer Mid-Peak		$0.09410	$0.68
Summer Off-Peak		$0.06987	$0.00
All Other Periods		$0.07163	$0.50

Table 20: Utility Rates

Once all of this information has been entered, further modifications can be made to the individual alternatives. Since TRACE does not include UFAD or displacement ventilation as default systems, the software is essentially overridden to model the expected operation. This includes altering supply air flow rates, outdoor air flow rates, operating temperatures and economizer operating conditions. These overrides should produce fairly accurate results, though it should be noted that the simulation may produce slightly different results from those of the actual system operation. Other modifications that are necessary include the addition of the new air handling units, and the new zoning assignments discussed earlier. Table 21 shows the resulting annual energy consumption for both the existing and the redesigned systems. This table also summarizes the differences in energy consumption between the two systems. Table 22 summarizes the annual operating costs associated with the differences in energy consumption. These operating costs have also been calculated by TRACE based on the utility data input from Table 20.

Component	Electrical Consumption [kWh]	Gas Consumption [kBTU]	Total Building Energy [kBtu/yr]	% of Total Building Energy
Existing System				
Primary Heating				
Boilers	-	331,301	331,301	1.3%
Other Heating Accessories	82,431	-	281,337	1.1%
Primary Cooling				
Chiller Compressors	789,499	-	2,694,562	10.8%
Cooling Tower Fans	981,379	-	3,349,445	13.5%
Condenser Water Pumps	956,400	-	3,264,192	13.1%
Other Cooling Accessories	5,829	-	19,894	0.1%
Auxiliary Equipment				
Supply Air Fans	970,533	-	3,312,428	13.3%
Pumps	499,310	-	1,704,146	6.9%
Lighting	2,238,382	-	7,605,467	30.6%
Receptacles	665,778	-	2,272,300	9.1%
Existing System Totals	**7,189,541**	**331,301**	**24,835,072**	**100.0%**
Existing System				
Primary Heating				
Boilers	-	1,150,956	150,956	0.5%
Other Heating Accessories	87,720	-	299,388	1.0%
Primary Cooling				
Chiller Compressors	952,299	-	3,250,195	10.4%
Cooling Tower Fans	1,360,574	-	4,643,639	14.8%
Condenser Water Pumps	1,373,153	-	4,686,571	15.0%
Other Cooling Accessories	8,369	-	28,563	0.1%
Auxiliary Equipment				
Supply Air Fans	1,910,060	-	6,519,033	20.8%
Pumps	537,602	-	1,834,835	5.9%
Lighting	2,228,383	-	7,605,467	24.3%
Receptacles	665,778	-	2,272,300	7.3%
Redesigned System Totals	**9,123,938**	**1,150,956**	**31,290,947**	**100.0%**
Total Difference Between Systems	**1,934,397**	**819,655**	**6,455,875**	

Table 21: Annual Energy Consumption Comparison

Utility	Annual Cost [$/yr]	Annual Cost per Square Foot [$/(SF*yr)]
Existing System		
Electricity	$627,893	$3.69
Natural Gas	$5,227	$0.03
Existing System Annual Cost	**$633,120**	**$3.72**
Redesigned System		
Electricity	$778,054	$4.57
Natural Gas	$13,707	$0.08
Redesigned System Annual Cost	**$791,761**	**$4.65**
Total Difference Between Systems	**$158,641**	**$0.93**

Table 22: Annual Operating Cost Comparison

Mechanical System Redesign Conclusions

While the previous sections of this report have outlined major design considerations, there are other criteria that must be considered. Perhaps the most important of these is humidity control. Typical overhead mixing systems control the amount of humidity in the building by conditioning air to around 55 °F. At this point, most of the moisture is condensed out of the air. As mentioned earlier, both UFAD and DV systems will have elevated supply air temperatures that are more in the neighborhood of 65 °F. As such, moisture in the air is not removed to the extent it is with lower supply air temperatures. While Las Vegas is typically considered a dry climate, there are certain periods of the year when humidity can become an issue. Unfortunately detailed weather data could not be found to determine the annual hours when outdoor humidity levels exceed those of the indoor design conditions. Preliminary estimates, however, indicate that some extent of dehumidification may be required for 5 - 10% of the year.

In order to maintain indoor humidity levels below 50% RH, some cooling will be required below the supply air temperature of 65 °F. From here, the air temperature will have to be raised sensibly to ensure that the air supplied to the space is within the comfort range mentioned earlier. The most likely way of achieving this would be through some form of coil by-pass. This would allow warmer return air to mix with the conditioned air, resulting in the necessary supply air temperature.

Based on the analysis performed for this report, it appears that Terminal 3 may not be an ideal application for underfloor air distribution and displacement ventilation systems. Research has shown that there is potential for energy savings from these systems, but this is not the case for Terminal 3. This contradiction is likely a result of the high space loads present in the area of redesign. It is important to recall that the gate holdrooms are all perimeter zones, and contain large areas of glass on the south façade. Since it has been assumed that 100% of this solar load is transmitted to the occupied zone, the chance for reducing supply air quantities diminishes.

Furthermore, the area of redesign is subject to very high occupant densities. The load from these occupants is often the most major contribution to total load on the mechanical system. Since occupant comfort is crucial in this facility, care has also been taken in reducing these loads. Detailed analysis of some interior zones with lower occupant densities shows that supply air flow rates may actually be reduced through the use of UFAD and DV systems. These reduced airflow rates would reduce annual operating costs, and would likely present a reasonable payback period for any increases in initial system cost.

As demonstrated earlier, there is a large increase in the amount of annual economizer operation. This free cooling would also assist in reducing annual operating costs. Furthermore, the reduction of outdoor air quantities ensures that less energy is used in providing ventilation air to the spaces. In the case of Terminal 3, all of these benefits were offset by the large increase in supply fan energy. If this fan energy was reduced, there is a strong likelihood that cost savings could become apparent for Terminal 3.

While it is not advisable to further reduce the occupied zone loads, other systems can be used to help offset the high cooling loads of the building. In particular, chilled beams could help reduce the sensible load in the space. By combining this sensible cooling approach with the redesigned UFAD and DV systems, supply air quantities could be reduced to a point where annual operating costs would also decrease.

One of the larger selling points for UFAD and DV systems is there impact on indoor air quality. In traditional mixing systems, contaminants are essentially diluted through a continuous mixing of air within the space. However, by effectively stratifying the space, the redesigned systems actually carry contaminants out of the occupied zone via thermal plumes. That is, as loads in the occupied zone warm the surrounding air buoyancy forces naturally carry this warmer air and any contaminants upward. Again, since occupant comfort is one of the major design goals for Terminal 3, this increased indoor air quality may make the system worth the initial investment.

While the increased initial and annual costs associated with the redesigned systems may seem high, one must remember that the total floor area of Terminal 3 is 1.8 million SF. When the cost analysis of this report is compared to the total project cost, the numbers seem slightly more reasonable. In fact, if small annual energy savings could be achieved, the redesigned systems would likely have a reasonable payback period. However, the evaluation of the redesigned systems is not based solely on the cost data. At this time, it seems that there is simply not enough research being performed on UFAD and DV systems. That being said, there are a variety of opinions and resources for designing these systems. Until some standardization is realized, these systems offer little guarantee on system performance. As a result, the redesigned systems are considered slightly risky.

Acoustical Design Breadth

Background Information and Existing Conditions

The existing design for Terminal 3 has taken into account potential acoustical problems that may result from the operation of mechanical equipment. It appears that the mains concern was the transmission of fan generated sound to the spaces via the ductwork. In an effort to minimize the transmission of this sound, both sound attenuators and duct lagging have been applied to most of the duct mains in the building. In the area of redesign, this design scheme has been applied to almost all of the existing air handling units with exception of AH-41 and AH-60.

In spaces where acoustics are critical, such attenuation efforts would likely be warranted. For example, the HVAC systems serving a performing arts space would likely require sound attenuation. This is done to ensure that noise from mechanical systems is not heard above the low ambient noise in the space. However, it is important to realize that Terminal 3 is part of a major airport, and such a facility will tend to have a large amount of ambient noise. As a result, it will be more difficult to hear the mechanical noise over these increased ambient levels. Furthermore, air velocities at the diffusers of the redesigned system have been lowered below those of the existing overhead system. As a result, many of these new diffusers have NC values that are lower than those of the existing system. Based on these various reasons, it is felt that further investigation of the acoustical design is warranted.

Analysis Performed

The first step in the acoustical investigation is to establish the minimum noise criteria (NC) for the space. Since the area of concern is part of a large public space, it is reasonable to assume a value of NC-45. Such a value is consistent with the expectations for other large densely populated areas including lobbies, public circulation, and other similar spaces. Once the minimum criterion for the space has been established, detailed analysis of the systems can be performed.

Similar to the existing acoustical treatments, the main concern of the redesigned system is the attenuation of fan generated sound that is transmitted through the ductwork. Since the ductwork for the various zones will be of similar size and layout configurations, the analysis is performed for a group of typical spaces only. In order to make this simplification as reasonable as possible, the analysis is performed for the system served by the fan with the highest sound levels. Comparison with fan data for the existing units indicates that AH-5R will utilize a fan with sound levels that exceed those of the other air handling units. As a result, the sound transmission of this system will be analyzed. If it can be proven that the layout of this ductwork provides adequate attenuation of the loudest fan, it is also reasonable to assume that similar layouts will provide adequate attenuation for fans with lower sound levels.

The actual system analysis for this section is performed using Trane Acoustics Program (TAP). This software allows for the duct layout to be easily modeled, and modified as necessary. As various components of the system are added to the layout, the resulting acoustical impacts are automatically calculated. In other words, TAP is capable of calculating both the sound attenuation and sound regeneration for various components including fans, ductwork, fittings, terminal units, diffusers, and many others. The data for these attenuations and regenerations is all based on research performed by

ASHRAE. The ASHRAE Applications Handbook provides acoustical data for typical components, and TAP simply uses these values to perform automated calculations.

Once again, in order to provide an accurate model of the proposed system layout, actual sound data for a fan of similar capacity will be used. From here, the expected layout and dimensions of ductwork will be required. While this detailed designed work has not been performed for this thesis, reasonable assumptions can be made with regards to the layout of the ductwork to serve the various spaces. For the typical system being analyzed, the air handling unit will be located in the mechanical penthouse. From here, the supply air duct will penetrate the slab of Level 3 and be routed through the return air plenum above the Level 2 ceiling. This duct will continue to follow the changes in ceiling heights as it travels through the ceiling space of the airside concourse. Upon reaching the gate holdrooms, the ductwork will be routed to the underfloor plenum through shafts located near the egress stairs. While a simpler layout could be achieved by routing all of the ductwork under the slab of Level 2, there is a limited amount of space below this slab. As a result, it may be difficult to accommodate the large duct sizes that will be required for large capacity systems. Furthermore, the structural members that create the transition between the traditional floor slab and the new access floor are a major obstruction that would have to be dealt with. As a result, the use of the Level 2 ceiling for this ductwork is felt to be more appropriate.

Conclusions

Based on the TAP output, it appears that the current sound attenuators and duct lagging will not be required on the redesigned system. This is true for both the supply air duct and return air ducts. Appendix B includes the detailed results of the TAP calculations. The general results of the analysis are also summarized here. TAP indicates that the resultant NC level of the critical supply air path will be NC-33. As mentioned earlier, the design goal was to achieve less than NC-45. Obviously the sound levels in the space are well within the design limit. Similarly, the return air path results in a value of NC-31. Again, since this analysis was performed for the highest fan sound levels, it can be assumed that all of the other systems no longer require sound attenuators or duct lagging. The NC graphs for both the supply and return ductwork are shown respectively in Figure 14.

In general, the decision to eliminate the sound attenuation in the ductwork also stems from some logical reasoning. As mentioned earlier, a building of this nature will have fairly high ambient noise levels. Airport gate holdrooms and concourse areas are often subject to large volumes of people producing ambient noise. More importantly, the fans of the air handling units all include variable speed drives. That being said, the airside systems are only operating at full capacity when the occupancy levels are highest. In other words, the mechanical system noise will likely vary at a rate similar to the ambient noise. At the same time, one must also consider other sources of ambient noise. Terminal 3 is equipped with a public announcement system that will commonly be in use. This system will be used to make general announcements through the terminal, and also will be used during the actual boarding process in the holdrooms. Finally, the transmission of outdoor noise into the space must also be considered. Large portions of the south façade consist of glass curtain wall. Such a material will have a low transmission loss, and some outdoor noise is likely to reach the indoor space. These noise sources include items such as the operation of jet engines.

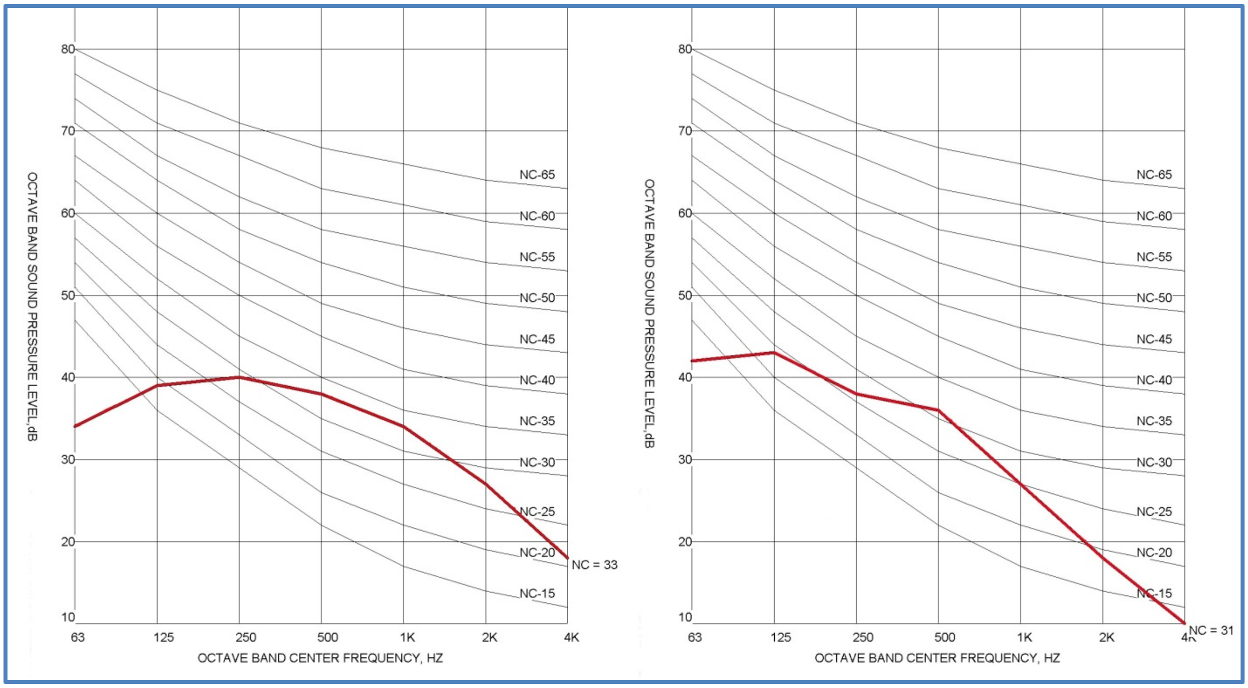

Figure 14: NC-33 Graph for Supply Air Fan; NC-31 Graph for Return Air Fan

Given these other noise sources that may be present in the area of interest, HVAC noise becomes less of an issue. If noise reductions from lower air velocities are taken into account, it becomes fairly clear that the sound attenuation efforts may be a bit excessive. That being said, this analysis indicates that the sound attenuators and duct lagging should be removed. Sound attenuation equipment can constitute a fair cost, as indicated in Table 23. These cost savings could help to offset some of the initial cost associated with the redesigned UFAD and DV systems. While these acoustical savings can not offset the total increase in HVAC cost, they are certainly helpful in reducing the price impacts.

It should be noted that the actual savings from removal of this equipment will likely be higher. This estimate was performed using data from R.S. Means 2008 since actual manufacturer's pricing could not be obtained. Since certain attenuator sizes were not listed in R.S. Means, the closest size unit was selected instead. Oftentimes, this unit was smaller in size and therefore likely underestimated in price. It should also be noted that Table 23 does not take into account any cost savings from the elimination of the duct lagging.

Air Handling Unit No.	Attenuator Size (W x H x L) [In]	Attenuator Flow [CFM]	Estimated Cost
AH-43 Return	108 x 36 x 60	45,000	$3,410.00
AH-43 Supply	84 x 36 x 60	45,000	$3,410.00
AH-45 Supply	84 x 42 x 60	50,000	$3,410.00
AH-47 Supply	84 x 36 x 60	50,000	$3,410.00
AH-50a Return	48 x 18 x 60	9,000	$1,273.00
AH-50a Return	48 x 18 x 60	9,000	$1,273.00
AH-50a Supply	48 x 36 x 60	30,000	$1,985.00
AH-50b Return	48 x 18 x 60	9,000	$1,273.00
AH-50b Return	48 x 18 x 60	9,000	$1,273.00
AH-50b Supply	60 x 30 x 60	30,000	$2,383.00
AH-52 Return	60 x 30 x 60	10,000	$2,383.00
AH-52 Return	60 x 30 x 60	10,000	$2,383.00
AH-54 Supply	84 x 42 x 60	50,000	$3,410.00
AH-57 Return	96 x 36 x 36	40,000	$3,410.00
AH-57 Supply	72 x 36 x 60	40,000	$3,410.00
AH-59 Return	84 x 42 x 36	40,000	$3,410.00
AH-59 Supply	72 x 36 x 60	40,000	$3,410.00
Total Cost for Existing Sound Attenuators			**$44,916.00**
Total Cost per Square Foot		**170,251** **SF**	**$0.26**

Table 23: Sound Attenuator Savings

Access Floor Design Breadth

Background Information

This design breadth focuses on the same areas discussed in the mechanical redesign. The existing floor design in the gate holdrooms is a concrete slab on metal deck assembly. The existing floor is also carpeted in these areas. The same concrete slab on metal deck assembly is used in other spaces within Terminal 3, though the floor finishes vary. Since such a floor system is not capable of accommodating the underfloor air distribution system mentioned in the mechanical redesign, modifications will be required.

Implementation of a UFAD system in the holdrooms will require a raised floor assembly. Addition of such a floor system will affect the construction cost, as well as the construction time for the project. Incorporation of the access floor will also have an impact on floor to ceiling heights within the space, as well as transitions to floor heights of adjoining spaces.

The analysis performed on this design breadth covers many elements and impacts of the system. Furthermore, the intended redesign must be evaluated from the perspective of many design disciplines. Since the raised floor system is intended to accommodate the mechanical redesign, many of the design criteria for the floor are a direct result of the HVAC system requirements.

Architectural and Structural Analysis

Since the UFAD system is limited to the gate holdrooms, the access floor will only be installed south of the airside concourse. The width of this area extends from column line A.0 to column line B, and is 37’-0”. With one exception, the raised floor will be installed over the entire length of the terminal between these two column lines. This exception is the public circulation area located between column line 26 and column line 29. This area is bound by major structural members, and will not include a UFAD system. As a result, the floor in this area is best left as the traditional concrete slab on metal deck. In addition to the holdrooms, there are several other spaces that are located within the area indicated. These spaces include electrical and telephone closets, office and storage spaces, and sterile circulation areas for international arrivals. These areas will be served by the UFAD systems, and therefore will also feature a raised floor.

While the access floor is required for the mechanical system redesign, there is a strong desire to minimize the architectural impact of such a floor system. As mentioned previously, the existing floor finish in this area is carpet. In order to maintain this finish, the new raised floor system will also feature a carpet finish. Another major architectural concern in this space is the affect on the floor to ceiling height. In order to minimize the impact of the access floor, the underfloor plenum will be kept at a depth of 1’-0” to 1’-6”. The final plenum size would be determined by the actual dimensions of equipment and any ductwork in the plenum, but preliminary sizing indicates a plenum height in this range would be sufficient.

In order to provide a smooth transition to adjacent areas, the concrete slab supporting the access floor must be at a height lower than the remainder of Level 2. Such a difference in slab elevation will allow for level floor heights once the raised floor is installed. Baggage handling equipment and ductwork in the Level 1 baggage handling areas require a significant amount of space. While there may be some room to lower the Level 2 slab, it is likely not advisable given the elevation difference required. Since ceiling height is minimal on Level 1, it makes more sense to increase the overall floor elevation of Level 2. In terms of maintaining floor to ceiling heights there are a couple of options. The most feasible solution is to simply reduce the height of the ceiling plenum. There is likely adequate space to do so, and such a change would maintain the ceiling height above finished floor. Additionally, the roof elevation could also be changed with the elevation of Level 2. Since this will require additional material and costs, it is assumed that this concept is less reasonable.

The other problem associated with changing the elevation of Level 2 is the impact it has on the jet bridges used to board aircraft at the gates. The current elevation of Level 2 has been determined based on a maximum differential between an airplane cabin door and the door connecting the jet bridge to the terminal. In the case of Terminal 3, the owner has requested to have the ability to serve McDonnell Douglas MD-80 aircraft. This is a smaller aircraft, and therefore sits lower to the ground. As a result, the elevation of Level 2 must also be lower. In order to accommodate this problem, there are a couple of solutions. The first solution would be to simply increase the size of the planes that can arrive and depart at Terminal 3. As a result, the smaller planes would be restricted to the existing terminals that are capable of accommodating the smaller aircraft. However, since this solution would likely not be appealing to the owner, other considerations must be given. The other possible solution to the problem is to create a longer jet bridge that would be capable of having a greater height differential. The only way to accomplish this would be to use a fixed section of jet bridge. This fixed section is typically only 20 feet in length, and with a maximum slope of 1:20 would only allow for a 1’-0” change in elevation. If a higher plenum height was required, it would be reasonable to assume that an extra six inches could be obtained by slightly lowering the elevation of the southern portion of Level 2 and then raising the remainder of the slab to create a smooth transition.

The addition of the fixed section of jet bridge also creates an additional problem. Current building codes actually classify the existing jet bridges as equipment. As such, no egress stairs are required for the jet bridges. However, once the fixed section of jet bridge is added, it becomes part of the building. In turn, this requires that egress stairs be added to each of the jet bridges. This is something that the architect strived to avoid, so this is also not an ideal solution. Unfortunately, there are likely not other solutions to this problem. In order to maintain ability to serve smaller aircraft at Terminal 3, it would likely be necessary to extend the jet bridges and add the egress stairs. While this is not ideal architecturally, there may be ways to help conceal the egress stairs. One must also consider that the stairs may not be in view of all passengers. Therefore, the impact may not be as great as one would expect.

Input from the structural engineer for the project indicates that the addition of the raised floor would likely not be a problem. While some brace frames and connection details would have to be manipulated, there are no major concerns with the proposed redesign. The structural redesign would simply have multiple structural members along column line B. One of these members would support the slab north of column line B, and the other would support the slab to the south. One advantage of the access floor is the elimination of walker duct serving the gaming machines in the gate holdroom areas. The access floor would now allow for electrical conductors to be located in the plenum space instead of being included in the concrete slab. This provides for greater flexibility should the machines ever be relocated, and also makes the installation process simpler.

Construction Cost and Scheduling Impacts

Along with the architectural and structural impacts of the raised floor, one must also consider the affect on cost and construction schedule. Since the raised floor will be incorporated over a large area, it is possible that the price of such a floor will be relatively high. At the same time, the access floor can also require a substantial amount of time and labor to install. As a part of the overall analysis of the access floor, both of these factors have been taken into account. Using R.S. Means 2008, both cost and scheduling impacts have been taken into account. Once again, the carpet covering of the gate holdrooms will be maintained, so this existing cost will also be taken into account. The results of the cost analysis are shown in Appendix D. Table D-1 shows the cost breakdown for the raised floor, which is estimated to cost approximately $985,000. Table D-2 shows the calculations for scheduling impacts as a result of the raised floor. The extra time required to install the floor will vary with the number of carpenters working on the floor, with eight carpenters being assumed for calculation purposes. Using only 8 carpenters, however, the floor will require several months to install. While this work can likely be completed while other construction is being performed, larger crews may help to reduce the scheduling impact of the additional floor.

Conclusions

While the raised floor is necessary for the installation of the underfloor air distribution system, it is apparent that there are significant impacts on other disciplines as a result. While structural impacts will likely be minimal, the architectural impacts of the access floor may be somewhat more prevalent. Moreover, the cost of the raised floor is quite significant. In fact, comparison with the mechanical system cost indicates that the addition of the raised floor is almost equal to the cost increase associated with the equipment for the redesigned mechanical system. That being said, the increase in initial investment has now essentially doubled. This higher first cost makes the redesigned systems less attractive from a financial standpoint, and the owner is less likely to be attracted to the redesigned system.

Final Conclusions and Recommendations

Once again, this report indicates that Terminal 3 is likely not an ideal facility for the use of either underfloor air distribution or displacement ventilation systems. Other facilities that are subject to lower, more predictable loads are likely better places to apply this technology. This is probably why UFAD systems are typically installed in office buildings. This is a building where the loads are relatively constant and can therefore be approximated fairly accurately.

The raised floor required for the UFAD system also has some negative impacts. In fact, the cost of the floor was comparable to that of the additional HVAC equipment required for the redesigned system. Since this investment can not be recovered through savings in annual energy costs, the cost is not exactly warranted. Furthermore, the access floor can have serious impacts on the architecture of the space. While many other buildings have greater flexibility for manipulating floor elevations, this is not the case for Terminal 3. As mentioned earlier, the baggage handling systems below the area of redesign make it unadvisable to lower the floor elevation by more than a few inches. At the same time, the jet bridges connecting the gate holdrooms to the aircraft dictate the maximum height of Level 2.

While the acoustical analysis indicates that sound attenuation equipment may be removed, the savings are fairly minimal. Compared to the other cost increases of the redesigned systems, this savings of approximately $50,000 is almost negligible.

In general, it appears that there is not yet enough information available to ensure the successful design of UFAD and DV systems. Given the size of Terminal 3, the owner is not likely to risk the use of this technology. Hopefully further research on these systems will lead to more consistent design guidelines that are proven accurate. As demonstrated earlier, both of these systems have a potential for major reductions in annual operating costs. The trick is to ensure that the building is suitable for such systems and that they can be guaranteed to function as expected.

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Appendix A – ASHRAE Standard 62.1-2007 Calculations

The following tables are provided as supporting calculations to the results mentioned earlier in this report. This appendix includes the analysis for both the existing and the redesigned systems in the area of interest. The following notes are referenced in the tables, and apply throughout this section.

Notes:

1. Duty Free occupancy is based on a load factor of 30 SF/person in accordance with the egress drawings. This provides for a higher occupant density than the ASHRAE Standard 62.1-2007 suggested value of 200 SF/person for a typical office space.
2. Interview occupancy is based on a load factor of 15 SF/person in accordance with the egress drawings. This provides for a higher occupant density than the ASHRAE Standard 62.1-2007 suggested value of 20 SF/person for a typical conference space.
3. Sterile Circulation occupancy is based on a load factor of 100 SF/person in accordance with the egress drawings.
4. Gate Holdroom occupancy is based on a load factor of 15 SF/person in accordance with the egress drawings. The resultant zone population is consistent with reasonable estimates for the passenger capacity of aircraft that will be served by these gates.
5. Airside Concourse occupancy is based on a load factor of 30 SF/person, which is a higher occupant density than the value of 100 SF/person indicated in the egress drawings. Since this space has the potential to serve as overflow from gate holdrooms, 30 SF/person serves as a more conservative estimate.
6. Gaming occupancy is based on fixed seating per architectural plans.
7. Concessions area occupancy is based on an occupancy of 30 SF per person in accordance with the egress drawings.
8. Restrooms are ventilated at an exhaust rate of 70 cfm/unit and Janitor's Storage at a rate of 1.00 cfm/unit according to Table 6-4 of ASHRAE Standard 62.1-2007. In accordance with ASHRAE Standard 62.1-2007 Section 6.2.8, there is no minimum value of outdoor airflow required to this space. It is assumed that makeup air will be provided as a combination of supply air direct from the air handler, and transfer air from adjacent spaces.
9. Public Circulation occupancy is based on a load factor of 30 SF/person, which is a higher occupant density than the value of 100 SF/person indicated in the egress drawings. Since this space has the potential to serve as overflow from TSA Waiting, 30 SF/person serves as a more conservative estimate.
10. TSA Waiting area occupancy is based on an occupancy of 15 SF per person in accordance with the egress drawings.
11. Trash Room is ventilated at an exhaust rate of 1.00 cfm/SF according to Table 6-4 of ASHRAE Standard 62.1-2007. In accordance with ASHRAE Standard 62.1-2007 Section 6.2.8, there is no minimum value of outdoor airflow required to this space. It is assumed that makeup air will be provided as a combination of supply air direct from the air handler, and transfer air from adjacent spaces.

Air Handling Unit Tag: AH-41														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**$R_{p,}$ [CFM/Person]**	**$V_{bz,}$ [CFM]**	**E_z**	**V_{oz} [CFM]**	**$V_{pz,}$[CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Airside Concourse	10,163	30	339	0.06	5	2,305	1.0	2,305	4,500	0.51	0.86			5
Gate 14 Electrical	88			0.06		5	1.0	5	280	0.02	1.36			-
Gate 15 Electrical	78			0.06		5	1.0	5	280	0.02	1.36			-
Gate 14 Holdroom	2,960	15	198	0.06	5	1,168	1.0	1,168	3,000	0.39	0.99			4
Gate 15 Holdroom	2,916	15	195	0.06	5	1,150	1.0	1,150	4,300	0.27	1.11			4
Total	**16,205**		**732**					**4,632**	**12,360**	**0.51**		**0.86**	**5,370**	

Table A-1: Ventilation Requirement Calculations for AH-41

Air Handling Unit Tag: AH-43														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**$R_{p,}$ [CFM/Person]**	**$V_{bz,}$ [CFM]**	**E_z**	**V_{oz} [CFM]**	**$V_{pz,}$[CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Airside Concourse	13,440	30	448	0.06	5	3,046	1.0	3,046	11,223	0.27	1.06			5
Concessions	2,183	30	73	0.18	7.5	940	1.0	940	1,000	0.94	0.39			7
Gate 12 Electrical	111			0.06		7	1.0	7	200	0.03	1.30			-
Gate 11 Holdroom	2,960	15	198	0.06	5	1,168	1.0	1,168	2,420	0.48	0.85			4
Gate 12 Holdroom	2,888	15	193	0.06	5	1,138	1.0	1,138	4,120	0.28	1.06			4
Gate 14 Holdroom	1,550	15	104	0.06	5	613	1.0	613	1,700	0.36	0.97			4
Corridor	1,360			0.06		82	1.0	82	255	0.32	1.01			-
Total	**24,492**		**1,016**					**6,994**	**20,918**	**0.94**		**0.39**	**17,755**	

Table A-2: Ventilation Requirement Calculations for AH-43

Air Handling Unit Tag: AH-45

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p, [CFM/Person]	V_{bz}, [CFM]	E_z	V_{oz} [CFM]	V_{pz},[CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Airside Concourse	11,520	30	384	0.06	5	2,611	1.0	2,611	6,750	0.39	1.08			5
Concessions	8,570	30	286	0.18	7.5	3,688	1.0	3,688	5,800	0.64	0.83			7
Gate 10 Electrical	88			0.06		5	1.0	5	80	0.07	1.40			-
Gate 10 / 11 Gaming	1,355		33	0.06	5	246	1.0	246	1,700	0.14	1.32			6
Gate 10 Holdroom	4,567	15	305	0.06	5	1,799	1.0	1,799	1,799	1.00	0.47			4
Gate 11 Holdroom	1,944	15	130	0.06	5	767	1.0	767	1,700	0.45	1.02			4
Corridor	2,191			0.06		131	1.0	131	680	0.19	1.27			-
Restrooms	3,373		50			0	1.0	0	1,255	0.00	1.47			8
Total	**33,608**		**1,188**					**9,248**	**19,764**	**1.00**		**0.47**	**19,764**	

Table A-3: Ventilation Requirement Calculations for AH-45

Air Handling Unit Tag: AH-47

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p, [CFM/Person]	V_{bz}, [CFM]	E_z	V_{oz} [CFM]	V_{pz},[CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Airside Concourse	11,118	30	371	0.06	5	2,522	1.0	2,522	8,748	0.29	0.99			5
Concessions	7,592	30	254	0.18	7.5	3,272	1.0	3,272	5,000	0.65	0.63			7
Gate 08 / 09 Gaming	636		33	0.06	5	203	1.0	203	1,700	0.12	1.16			6
Gate 8 Holdroom	3,236	15	216	0.06	5	1,274	1.0	1,274	2,500	0.51	0.77			4
Gate 9 Holdroom	3,312	15	221	0.06	5	1,304	1.0	1,304	3,300	0.40	0.89			4
Corridor	2,263			0.06		136	1.0	136	550	0.25	1.04			-
Gate 08 Electrical	89			0.06		5	1.0	5	80	0.07	1.22			-
Total	**28,246**		**1,095**					**6,194**	**21,878**	**0.65**		**0.63**	**9,850**	

Table A-4: Ventilation Requirement Calculations for AH-47

Air Handling Unit Tag: AH-50a														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**$R_{p,}$ [CFM/Person]**	**$V_{bz,}$ [CFM]**	**E_z**	**V_{oz} [CFM]**	**$V_{pz,}$[CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Public Circulation	5,992	30	200	0.06	5	1,360	1.0	1,360	6,410	0.21	0.99			9
TSA Security Waiting	2,225	15	149	0.06	5	879	1.0	879	4,660	0.19	1.01			10
Corridor	392			0.06		24	1.0	24	200	0.12	1.09			-
Offices	124	30	5	0.06	5	32	1.0	32	63	0.52	0.68			-
Storage	177			0.12		21	1.0	21	88	0.24	0.96			-
Total	**8,910**		**354**					**2,315**	**11,420**	**0.52**		**0.68**	**3,386**	

Table A-5: Ventilation Requirement Calculations for AH-50a

Air Handling Unit Tag: AH-50b														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**$R_{p,}$ [CFM/Person]**	**$V_{bz,}$ [CFM]**	**E_z**	**V_{oz} [CFM]**	**$V_{pz,}$[CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Public Circulation	5,962	30	199	0.06	5	1,353	1.0	1,353	6,410	0.21	0.99			9
TSA Security Waiting	2,225	15	149	0.06	5	879	1.0	879	4,740	0.19	1.02			10
Offices	160	100	2	0.06	5	20	1.0	20	80	0.25	0.96			-
Total	**8,347**		**350**					**2,251**	**11,230**	**0.25**		**0.96**	**2,356**	

Table A-6: Ventilation Requirement Calculations for AH-50b

Air Handling Unit Tag: AH-52

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	$R_{p,}$ [CFM/Person]	$V_{bz,}$ [CFM]	E_z	V_{oz} [CFM]	$V_{pz,}$[CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Airside Concourse	11,495	30	384	0.06	5	2,610	1.0	2,610	8,063	0.32	1.09			5
Concessions	3,667	30	123	0.18	7.5	1,583	1.0	1,583	3,668	0.43	0.98			7
Gate 07 Electrical	88			0.06		5	1.0	5	80	0.07	1.35			-
Gate 06 Electrical	101			0.06		6	1.0	6	80	0.08	1.34			-
Gate 05 / 06 Sterile Circ	2,338	100	24	0.06	5	260	1.0	260	3,105	0.08	1.33			3
Gate 7 Holdroom	2,939	15	196	0.06	5	1,156	1.0	1,156	1,156	1.00	0.42			4
Gate 6 Holdroom	6,311	15	421	0.06	5	2,484	1.0	2,484	4,400	0.56	0.85			4
Secure Corridor	2,446			0.06		147	1.0	147	510	0.29	1.13			-
First Class Lounge Shell	10,567	30	353	0.06	5	2,399	1.0	2,399	4,540	0.53	0.89			-
Total	**39,952**		**1,501**					**10,650**	**25,601**	**1.00**		**0.42**	**25,601**	

Table A-7: Ventilation Requirement Calculations for AH-52

Air Handling Unit Tag: AH-54

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	$R_{p,}$ [CFM/Person]	$V_{bz,}$ [CFM]	E_z	V_{oz} [CFM]	$V_{pz,}$[CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Airside Concourse	11,520	30	384	0.06	5	2,611	1.0	2,611	8,050	0.32	1.06			5
Concessions	7,371	30	246	0.18	7.5	3,172	1.0	3,172	6,670	0.48	0.91			7
Gate 03 / 04 Sterile Circ	985	100	10	0.06	5	109	1.0	109	1,700	0.06	1.32			3
Gate 4 Holdroom	6,251	15	417	0.06	5	2,460	1.0	2,460	3,875	0.63	0.75			4
Gate 5 Holdroom	2,539	15	170	0.06	5	1,002	1.0	1,002	2,500	0.40	0.99			4
Corridor	2,194			0.06		132	1.0	132	510	0.26	1.13			-
Gate 05 / 06 Duty Free	60	30	2	0.06	5	14	1.0	14	30	0.45	0.93			1
Gate 05 / 06 Interview	70	15	5	0.06	5	29	1.0	29	35	0.83	0.55			2
Gate 06 Wheeelchair Stor	81			0.12		10	1.0	10	20	0.49	0.90			-
Restrooms	3,173		50			0	1.0	0	1,255	0.00	1.39			8
Total	**34,244**		**1,284**					**9,539**	**24,645**	**0.83**		**0.55**	**17,257**	

TableA-8: Ventilation Requirement Calculations for AH-54

Air Handling Unit Tag: AH-57

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	$R_{p,}$ [CFM/Person]	$V_{bz,}$ [CFM]	E_z	V_{oz} [CFM]	$V_{pz,}$[CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Airside Concourse	9,600	30	320	0.06	5	2,176	1.0	2,176	5,625	0.39	1.07			5
Concessions	8,491	30	284	0.18	7.5	3,658	1.0	3,658	6,300	0.58	0.88			7
Gate 03 / 04 Duty Free	58	30	2	0.06	5	13	1.0	13	30	0.45	1.01			1
Gate 03 / 04 Interview	67	15	5	0.06	5	29	1.0	29	35	0.83	0.63			2
Gate 03 / 04 Wheelchair Stor	79			0.12		9	1.0	9	30	0.32	1.15			-
Gate 3 Holdroom	6,791	15	453	0.06	5	2,672	1.0	2,672	5,100	0.52	0.94			4
Corridor	1,778			0.06		107	1.0	107	255	0.42	1.04			-
Gate 03 / 04 Sterile Circ	985	100	10	0.06	5	109	1.0	109	1,650	0.07	1.40			3
Total	**27,849**		**1,074**					**8,775**	**19,025**	**0.83**		**0.63**	**13,882**	

Table A-9: Ventilation Requirement Calculations for AH-57

Air Handling Unit Tag: AH-59

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	$R_{p,}$ [CFM/Person]	$V_{bz,}$ [CFM]	E_z	V_{oz} [CFM]	$V_{pz,}$[CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Airside Concourse	9,600	30	320	0.06	5	2,176	1.0	2,176	5,625	0.39	0.92			5
Concessions	3,480	30	116	0.18	7.5	1,496	1.0	1,496	4,730	0.32	0.99			7
Gate 2 Holdroom	4,178	15	279	0.06	5	1,646	1.0	1,646	4,450	0.37	0.93			4
Gate 01 / 02 Sterile Circ	880	100	9	0.06	5	98	1.0	98	1,725	0.06	1.25			3
Corridor	1,711			0.06		103	1.0	103	510	0.20	1.10			-
Restrooms	3,146		44			0	1.0	0	1,130	0.00	1.30			8
Total	**22,995**		**768**					**5,519**	**18,170**	**0.39**		**0.92**	**6,019**	

Table A-10: Ventilation Requirement Calculations for AH-59

Air Handling Unit Tag: AH-60														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**R_p, [CFM/Person]**	**V_{bz}, [CFM]**	**E_z**	**V_{oz} [CFM]**	**V_{pz},[CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Airside Concourse	9,372	30	313	0.06	5	2,127	1.0	2,127	5,625	0.38	0.82			5
Gate 1 & 2 Sterile Corridor	1,498	100	15	0.06	5	165	1.0	165	2,550	0.06	1.13			3
Gate 1 Holdroom	3,759	15	251	0.06	5	1,481	1.0	1,481	5,400	0.27	0.92			4
Concessions	3,209	30	107	0.18	7.5	1,380	1.0	1,380	2,000	0.69	0.51			7
Gate 01 / 02 Duty Free	63	30	3	0.06	5	19	1.0	19	30	0.63	0.57			1
Gate 01 / 02 Interview	70	15	5	0.06	5	29	1.0	29	35	0.83	0.36			2
Gate 01 / 02 Wheelchair Stor	76			0.12		9	1.0	9	30	0.30	0.89			-
Trash Room	225					0	1.0	0	50	0.00	1.20			11
Total	**18,272**		**694**					**3,083**	**15,720**	**0.83**		**0.36**	**8,520**	

Table A-11: Ventilation Requirement Calculations for AH-60

Air Handling Unit Tag: AH-1R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 01 / 02 Duty Free	63	30	3	0.06	5	19	1.2	16	70	0.22	0.88			1
Gate 01 / 02 Interview	70	15	5	0.06	5	29	1.2	24	115	0.21	0.89			2
Gate 01 / 02 Wheelchair Stor	76			0.12		9	1.2	8	50	0.15	0.95			-
Gate 01 / 02 Sterile Circ	2,378	100	24	0.06	5	263	1.2	219	5,075	0.04	1.06			3
Gate 01 Holdroom	3,759	15	251	0.06	5	1,481	1.2	1,234	8,790	0.14	0.97			4
Total	**6,346**		**283**					**1,500**	**14,100**	**0.22**		**0.88**	**1,699**	

Table A-12: Ventilation Requirement Calculations for AH-1R

Air Handling Unit Tag: AH-2R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 01 Airside Concourse	9,600	30	320	0.06	5	2,176	1.2	1,813	8,548	0.21	1.02			5
Gate 02 Airside Concourse (East)	5,245	30	175	0.06	5	1,190	1.2	991	3,455	0.29	0.95			5
Total	**14,845**		**495**					**2,805**	**12,003**	**0.29**		**0.95**	**2,963**	

Table A-13: Ventilation Requirement Calculations for AH-2R

Air Handling Unit Tag: AH-3R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 03 / 04 Duty Free	58	30	2	0.06	5	13	1.2	11	65	0.17	1.01			1
Gate 03 / 04 Interview	67	15	5	0.06	5	29	1.2	24	110	0.22	0.96			2
Gate 03 / 04 Wheelchair Stor	79			0.12		9	1.2	8	25	0.32	0.87			-
Gate 03 / 04 Sterile Circ	1,971	100	20	0.06	5	218	1.2	182	4,080	0.04	1.14			3
Gate 02 Holdroom	4,178	15	279	0.06	5	1,646	1.2	1,371	6,668	0.21	0.98			4
Gate 03 Holdroom	6,791	15	453	0.06	5	2,672	1.2	2,227	10,095	0.22	0.96			4
Total	**13,144**		**759**					**3,824**	**21,043**	**0.32**		**0.87**	**4,417**	

Table A-14: Ventilation Requirement Calculations for AH-3R

Air Handling Unit Tag: AH-4R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 02 Airside Concourse (West)	5,315	30	178	0.06	5	1,209	1.2	1,007	3,500	0.29	0.99			5
Gate 03 Airside Concourse	9,600	30	320	0.06	5	2,176	1.2	1,813	6,423	0.28	0.99			5
Gate 04 Airside Concourse (East)	1,082	30	37	0.06	5	250	1.2	208	1,000	0.21	1.07			5
Total	**15,997**		**535**					**3,029**	**10,923**	**0.29**		**0.99**	**3,061**	

Table A-15: Ventilation Requirement Calculations for AH-4R

Air Handling Unit Tag: AH-5R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 05 / 06 Duty Free	60	30	2	0.06	5	14	1.2	11	68	0.17	1.01			1
Gate 05 / 06 Interview	70	15	5	0.06	5	29	1.2	24	115	0.21	0.96			2
Gate 05 Wheelchair Stor	81			0.12		10	1.2	8	25	0.32	0.85			-
Gate 05 / 06 Sterile Circ	2,338	100	24	0.06	5	260	1.2	217	5,063	0.04	1.13			3
Gate 04 Holdroom	6,251	15	417	0.06	5	2,460	1.2	2,050	9,035	0.23	0.95			4
Gate 05 Holdroom	2,539	15	170	0.06	5	1,002	1.2	835	3,798	0.22	0.95			4
Total	**11,339**		**618**					**3,146**	**18,103**	**0.32**		**0.85**	**3,702**	

Table A-16: Ventilation Requirement Calculations for AH-5R

Air Handling Unit Tag: AH-6R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 04 Airside Concourse (West)	9,057	30	302	0.06	5	2,053	1.2	1,711	8,370	0.20	1.00			5
Gate 05 Airside Concourse	4,261	30	143	0.06	5	971	1.2	809	3,938	0.21	1.00			5
Total	**13,318**		**445**					**2,520**	**12,308**	**0.21**		**1.00**	**2,522**	

Table A-17: Ventilation Requirement Calculations for AH-6R

Air Handling Unit Tag: AH-7R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 06 Electrical	101			0.06		6	1.2	5	130	0.04	1.18			-
Gate 06 Holdroom	6,311	15	421	0.06	5	2,484	1.2	2,070	8,763	0.24	0.99			4
Gate 07 Boarding Corridor	318	100	4	0.06	5	39	1.2	33	288	0.11	1.11			4
Gate 07 Electrical	88			0.06		5	1.2	4	113	0.04	1.18			-
Gate 07 Holdroom	2,939	15	196	0.06	5	1,156	1.2	964	4,595	0.21	1.01			4
Total	**9,757**		**621**					**3,075**	**13,888**	**0.24**		**0.99**	**3,121**	

Table A-18: Ventilation Requirement Calculations for AH-7R

Air Handling Unit Tag: AH-8R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 06 / 07 Airside Concourse	10,560	30	352	0.06	5	2,394	1.2	1,995	6,885	0.29	1.00			5
Total	**10,560**		**352**					**1,995**	**6,885**	**0.29**		**1.00**	**1,995**	

Table A-19: Ventilation Requirement Calculations for AH-8R

Air Handling Unit Tag: AH-9R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 08 / 09 Gaming	636		33	0.06	5	203	1.2	169	1,493	0.11	1.07			6
Gate 08 Electrical	89			0.06		5	1.2	4	115	0.04	1.15			-
Gate 08 Holdroom	3,236	15	216	0.06	5	1,274	1.2	1,062	5,003	0.21	0.97			4
Gate 08 Wheelchair Stor	257			0.12		31	1.2	26	280	0.09	1.09			-
Gate 09 Holdroom	3,312	15	221	0.06	5	1,304	1.2	1,086	5,690	0.19	1.00			4
Gate 09 Telecomm	22					0	1.2	0	30	0.00	1.19			-
Total	**7,552**		**470**					**2,348**	**12,610**	**0.21**		**0.97**	**2,411**	

Table A-20: Ventilation Requirement Calculations for AH-9R

Air Handling Unit Tag: AH-10R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 08 Airside Concourse	4,800	30	160	0.06	5	1,088	1.2	907	3,110	0.29	1.29			5
Gate 09 Airside Concourse (East)	4,708	30	157	0.06	5	1,067	1.2	890	4,355	0.20	1.37			5
Total	**9,508**		**317**					**1,796**	**3,110**	**0.29**		**1.29**	**1,397**	

Table A-21: Ventilation Requirement Calculations for AH-10R

Air Handling Unit Tag: AH-11R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 10 / 11 Gaming	1,355		33	0.06	5	246	1.2	205	1,498	0.14	1.06			6
Gate 10 Electrical	88			0.06		5	1.2	4	100	0.04	1.15			-
Gate 10 Holdroom	4,567	15	305	0.06	5	1,799	1.2	1,499	7,343	0.20	0.99			4
Gate 11 Holdroom	4,904	15	327	0.06	5	1,929	1.2	1,608	7,788	0.21	0.99			4
Total	**10,914**		**665**					**3,317**	**16,728**	**0.21**		**0.99**	**3,344**	

Table A-22: Ventilation Requirement Calculations for AH-11R

Air Handling Unit Tag: AH-12R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 09 Airside Concourse (West)	2,973	30	100	0.06	5	678	1.2	565	2,750	0.21	1.00			5
Gate 10 Airside Concourse	7,679	30	256	0.06	5	1,741	1.2	1,451	7,105	0.20	1.00			5
Total	**10,652**		**356**					**2,016**	**9,855**	**0.21**		**1.00**	**2,018**	

Table A-23: Ventilation Requirement Calculations for AH-11R

Air Handling Unit Tag: AH-13R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 11 Airside Concourse	7,200	30	240	0.06	5	1,632	1.2	1,360	6,708	0.20	1.00			5
Gate 12 Airside Concourse (East)	5,637	30	188	0.06	5	1,278	1.2	1,065	5,250	0.20	1.00			5
Total	**12,837**		**428**					**2,425**	**11,958**	**0.20**		**1.00**	**2,425**	

Table A-24: Ventilation Requirement Calculations for AH-13R

Air Handling Unit Tag: AH-14R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 12 Electrical	111			0.06		7	1.2	6	130	0.04	1.11			-
Gate 12 Holdroom	2,888	15	193	0.06	5	1,138	1.2	949	7,468	0.13	1.02			4
Gate 14 Electrical	88			0.06		5	1.2	4	100	0.04	1.10			-
Gate 14 Holdroom	4,510	15	301	0.06	5	1,776	1.2	1,480	7,268	0.20	0.94			4
Gate 15 Electrical	78			0.06		5	1.2	4	90	0.04	1.10			-
Gate 15 Holdroom	2,916	15	195	0.06	5	1,150	1.2	958	7,928	0.12	1.03			4
Total	**10,591**		**689**					**3,400**	**22,983**	**0.20**		**0.94**	**3,601**	

Table A-25: Ventilation Requirement Calculations for AH-14R

Air Handling Unit Tag: AH-15R

Space Type	A_z [SF]	Occupant Load Factor [SF/Person]	P_z	R_a [CFM/SF]	R_p [CFM/Person	V_{bz} [CFM]	E_z	V_{oz} [CFM]	V_{pz} [CFM]	Z_p	E_{vz}	E_v	V_{ot} [CFM]	Notes
Gate 12 Airside Concourse (West)	1,563	30	53	0.06	5	359	1.2	299	1,458	0.21	1.05			5
Gate 14 / 15 Airside Concourse	11,520	30	384	0.06	5	2,611	1.2	2,176	8,413	0.26	0.99			5
Total	**13,083**		**437**					**2,475**	**9,870**	**0.26**		**0.99**	**2,495**	

Table A-26: Ventilation Requirement Calculations for AH-15R

Air Handling Unit Tag: AH-16R														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**R_p [CFM/Person**	**V_{bz} [CFM]**	**E_z**	**V_{oz} [CFM]**	**V_{pz} [CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Secure Corridor	3,551			0.06		213	1.0	213	935	0.23	1.54			-
Concessions	14,511	30	484	0.18	7.5	6,242	1.0	6,242	6,242	1.00	0.77			7
Restrooms	3,373		50			0	1.0	0	1,255	0.00	1.77			8
Total	**21,435**		**534**					**6,455**	**8,432**	**1.00**		**0.77**	**8,432**	

Table A-27: Ventilation Requirement Calculations for AH-16R

Air Handling Unit Tag: AH-17R														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**R_p [CFM/Person**	**V_{bz} [CFM]**	**E_z**	**V_{oz} [CFM]**	**V_{pz} [CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Secure Corridor	2,655			0.06		159	1.0	159	750	0.21	1.12			-
Concessions	7,592	30	254	0.18	7.5	3,272	1.0	3,272	5,000	0.65	0.68			7
Office	124	30	5	0.06	5	32	1.0	32	63	0.52	0.82			-
Storage	177			0.12		21	1.0	21	88	0.24	1.09			-
Public Circulation	5,992	30	200	0.06	5	1,360	1.0	1,360	6,410	0.21	1.13			9
TSA Waiting	2,225	15	149	0.06	5	879	1.0	879	4,660	0.19	1.15			10
Total	**18,765**		**608**					**5,723**	**16,970**	**0.65**		**0.68**	**8,380**	

Table A-28: Ventilation Requirement Calculations for AH-17R

Air Handling Unit Tag: AH-18R														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**R_p [CFM/Person**	**V_{bz} [CFM]**	**E_z**	**V_{oz} [CFM]**	**V_{pz} [CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Secure Corridor	2,446			0.06		147	1.0	147	510	0.29	1.03			-
Concessions	3,667	30	123	0.18	7.5	1,583	1.0	1,583	3,668	0.43	0.89			7
Office	160	100	2	0.06	5	20	1.0	20	80	0.25	1.07			-
Public Circulation	5,962	30	199	0.06	5	1,353	1.0	1,353	6,410	0.21	1.11			9
First Class Lounge Shell	10,567	30	353	0.06	5	2,399	1.0	2,399	4,540	0.53	0.79			-
TSA Waiting	2,225	15	149	0.06	5	879	1.0	879	4,740	0.19	1.13			10
Total	**25,027**		**826**					**6,379**	**19,948**	**0.53**		**0.79**	**8,061**	

Table A-29: Ventilation Requirement Calculations for AH-18R

Air Handling Unit Tag: AH-19R														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**R_p [CFM/Person**	**V_{bz} [CFM]**	**E_z**	**V_{oz} [CFM]**	**V_{pz} [CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Secure Corridor	2,194			0.06		132	1.0	132	510	0.26	1.13			-
Concessions	7,371	30	246	0.18	7.5	3,172	1.0	3,172	6,670	0.48	0.92			7
Restrooms	3,173		50			0	1.0	0	1,255	0.00	1.39			8
Total	**12,738**		**296**					**3,303**	**8,435**	**0.48**		**0.92**	**3,606**	

Table A-30: Ventilation Requirement Calculations for AH-19R

Air Handling Unit Tag: AH-20R														
Space Type	**A_z [SF]**	**Occupant Load Factor [SF/Person]**	**P_z**	**R_a [CFM/SF]**	**R_p [CFM/Person**	**V_{bz} [CFM]**	**E_z**	**V_{oz} [CFM]**	**V_{pz} [CFM]**	**Z_p**	**E_{vz}**	**E_v**	**V_{ot} [CFM]**	**Notes**
Secure Corridor	3,489			0.06		209	1.0	209	765	0.27	1.15			-
Concessions	15,180	30	506	0.18	7.5	6,527	1.0	6,527	13,030	0.50	0.93			7
Storage	1,292			0.12		155	1.0	155	1,183	0.13	1.30			-
Restrooms	3,146		50			0	1.0	0	1,130	0.00	1.43			8
Trash Room	225	300	1			0	1.0	0	50	0.00	1.43			11
Total	**23,332**		**556**					**6,892**	**16,108**	**0.50**		**0.93**	**7,435**	

Table A-31: Ventilation Requirement Calculations for AH-20R

Appendix B – Zone Assignments for Air Handling Units

While a summary of the redesigned air handling units has been presented earlier, this section is intended to provide a more detailed breakdown of the room assignments for the various units. The tables in this section summarize all of the redesigned air handling units. This includes those to serve the UFAD and DV systems, as well as those that will serve the remaining overhead systems in the area of focus.

Air Handling Unit Tag: AH-1R		
Room No.	**Room Name**	**SA Rate [CFM]**
21113	Gate 01 / 02 Duty Free	140
21112	Gate 01 / 02 Interview	230
21114	Gate 01 / 02 Wheelchair Stor	100
21107	Gate 01 / 02 Sterile Circ	10,150
21202	Gate 01 Holdroom	17,580
	Total	**28,200**
Unit Location: Current location of AH-60		

Table B-1: Supply Air Flow Rate Zone Sums for AH-1R

Air Handling Unit Tag: AH-2R		
Room No.	**Room Name**	**SA Rate [CFM]**
21201	Gate 01 Airside Concourse	17,095
21101	Gate 02 Airside Concourse (East)	6,910
	Total	**24,005**
Unit Location: Above egress stairs #21 and #22		

Table B-2: Supply Air Flow Rate Zone Sums for AH-2R

Air Handling Unit Tag: AH-3R		
Room No.	**Room Name**	**SA Rate [CFM]**
20912	Gate 03 / 04 Duty Free	130
20911	Gate 03 / 04 Interview	220
20905	Gate 03 / 04 Sterile Circ	8,160
21114	Gate 03 / 04 Wheelchair Stor	50
21102	Gate 02 Holdroom	13,335
21002	Gate 03 Holdroom	20,190
	Total	**42,085**
Unit Location: Current location of AH-57		

Table B-3: Supply Air Flow Rate Zone Sums for AH-3R

Air Handling Unit Tag: AH-4R		
Room No.	**Room Name**	**SA Rate [CFM]**
21101	Gate 02 Airside Concourse (West)	7,000
21001	Gate 03 Airside Concourse	12,845
20801	Gate 04 Airside Concourse (East)	2,000
	Total	**21,845**
Unit Location: Above egress stairs #19 and #20		

Table B-4: Supply Air Flow Rate Zone Sums for AH-4R

Air Handling Unit Tag: AH-5R		
Room No.	**Room Name**	**SA Rate [CFM]**
20809	Gate 05 / 06 Duty Free	135
20808	Gate 05 / 06 Interview	230
20803	Gate 05 / 06 Sterile Circ	10,125
20610	Gate 05 Wheelchair Stor	50
20811	Gate 04 Holdroom	18,070
20811	Gate 05 Holdroom	7,595
	Total	**36,205**
Unit Location: Available penthouse space		

Table B-5: Supply Air Flow Rate Zone Sums for AH-5R

Air Handling Unit Tag: AH-6R		
Room No.	**Room Name**	**SA Rate [CFM]**
20801	Gate 04 Airside Concourse (West)	16,740
20901	Gate 05 Airside Concourse	7,875
	Total	**24,615**
Unit Location: Above egress stairs #14 and #15		

Table B-6: Supply Air Flow Rate Zone Sums for AH-6R

Air Handling Unit Tag: AH-7R		
Room No.	**Room Name**	**SA Rate [CFM]**
20706	Gate 06 Electrical	260
20703	Gate 06 Holdroom	17,525
20615	Gate 07 Boarding Corridor	575
20614	Gate 07 Electrical	225
20702	Gate 07 Holdroom	9,190
	Total	**27,775**
Unit Location: Current location of AH-52		

Table B-7: Supply Air Flow Rate Zone Sums for AH-7R

Air Handling Unit Tag: AH-8R		
Room No.	**Room Name**	**SA Rate [CFM]**
20701	Gate 06 / 07 Airside Concourse	13,770
	Total	**13,770**
Unit Location: Above egress stairs #12 and #13		

Table B-8: Supply Air Flow Rate Zone Sums for AH-8R

Air Handling Unit Tag: AH-9R		
Room No.	**Room Name**	**SA Rate [CFM]**
20503	Gate 08 / 09 Gaming	2,985
20502	Gate 08 Electrical	230
20504	Gate 08 Holdroom	10,005
20624	Gate 08 Wheelchair Stor	560
20502	Gate 09 Holdroom	11,380
20471	Gate 09 Telecomm	60
	Total	**25,220**
Unit Location: Current location of AH-47		

Table B-9: Supply Air Flow Rate Zone Sums for AH-9R

Air Handling Unit Tag: AH-10R		
Room No.	**Room Name**	**SA Rate [CFM]**
20511	Gate 08 Airside Concourse	6,220
20401	Gate 09 Airside Concourse (East)	8,710
	Total	**14,930**
Unit Location: Above egress stairs #10 and #11		

Table B-10: Supply Air Flow Rate Zone Sums for AH-10R

Air Handling Unit Tag: AH-11R		
Room No.	**Room Name**	**SA Rate [CFM]**
20307	Gate 10 / 11 Gaming	2,995
20404	Gate 10 Electrical	200
20402	Gate 10 Holdroom	14,685
20307	Gate 11 Holdroom	15,575
	Total	**33,455**
Unit Location: Current location of AH-43		

Table B-11: Supply Air Flow Rate Zone Sums for AH-11R

Air Handling Unit Tag: AH-12R		
Room No.	**Room Name**	**SA Rate [CFM]**
20401	Gate 09 Airside Concourse (West)	5,500
20501	Gate 10 Airside Concourse	14,210
	Total	**19,710**
Unit Location: Above egress stairs #08 and #09		

Table B-12: Supply Air Flow Rate Zone Sums for AH-12R

Air Handling Unit Tag: AH-13R		
Room No.	**Room Name**	**SA Rate [CFM]**
20301	Gate 11 Airside Concourse	13,415
20201	Gate 12 Airside Concourse (East)	10,500
	Total	**23,915**
Unit Location: Above egress stairs #06 and #07		

Table B-13: Supply Air Flow Rate Zone Sums for AH-13R

Air Handling Unit Tag: AH-14R		
Room No.	**Room Name**	**SA Rate [CFM]**
20302	Gate 12 Electrical	260
20203	Gate 12 Holdroom	14,935
20105	Gate 14 Electrical	200
20103	Gate 14 Holdroom	14,535
20104	Gate 15 Electrical	180
20102	Gate 15 Holdroom	15,855
	Total	**45,965**
Unit Location: Current location of AH-41		

Table B-14: Supply Air Flow Rate Zone Sums for AH-14R

Air Handling Unit Tag: AH-15R		
Room No.	**Room Name**	**SA Rate [CFM]**
20201	Gate 12 Airside Concourse (West)	2,915
20101	Gate 14 / 15 Airside Concourse	16,825
	Total	**19,740**
Unit Location: Above egress stairs #04 and #05		

Table B-15: Supply Air Flow Rate Zone Sums for AH-15R

Air Handling Unit Tag: AH-16R	
Existing System Assignment	**SA Rate [CFM]**
AH-43	3,110
AH-45	12,870
Total	**15,980**
Unit Location: Current location of AH-45	

Table B-16: Supply Air Flow Rate Zone Sums for AH-16R

Air Handling Unit Tag: AH-17R	
Existing System Assignment	**SA Rate [CFM]**
AH-47	11,100
AH-50a	22,840
Total	**33,940**
Unit Location: Current location of AH-50a	

Table B-17: Supply Air Flow Rate Zone Sums for AH-17R

Air Handling Unit Tag: AH-18R	
Existing System Assignment	**SA Rate [CFM]**
AH-50b	22,985
AH-52	17,435
Total	**40,420**
Unit Location: Current location of AH-50b	

Table B-18: Supply Air Flow Rate Zone Sums for AH-18R

Air Handling Unit Tag: AH-19R	
Existing System Assignment	**SA Rate [CFM]**
AH-54	16,870
Total	**16,870**
Unit Location: Current location of AH-54	

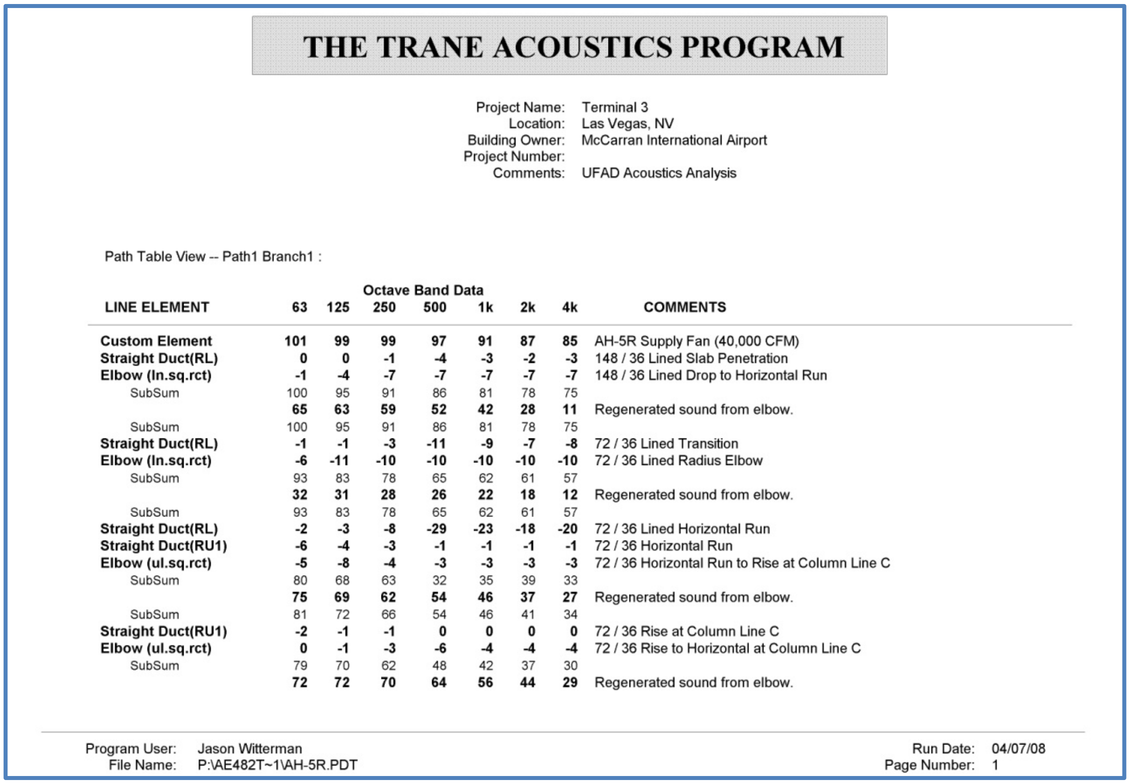
Table B-19: Supply Air Flow Rate Zone Sums for AH-19R

Air Handling Unit Tag: AH-20R	
Existing System Assignment	**SA Rate [CFM]**
AH-57	13,110
AH-59	12,740
AH-60	4,000
Total	**29,850**
Unit Location: Current location of AH-59	

Table B-20: Supply Air Flow Rate Zone Sums for AH-20R

Appendix C – Trane Acoustical Program Calculation Results

While the resultant NC values have been summarized earlier, this section is intended to provide a more detailed breakdown of the calculations performed for the acoustical investigations. Figure C-1 and Figure C-2 show the individual attenuation and regeneration values for the various distribution components.



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                         THE TRANE ACOUSTICS PROGRAM

                                   Project Name:  Terminal 3
                                       Location:  Las Vegas, NV
                                 Building Owner:  McCarran International Airport
                                 Project Number:
                                       Comments:  UFAD Acoustics Analysis


 Path Table View -- Path1 Branch1 :

                                  Octave Band Data
 LINE ELEMENT            63  125  250  500   1k   2k   4k        COMMENTS
 ------------------------------------------------------------------------------------------
 Custom Element         101   99   99   97   91   87   85   AH-5R Supply Fan (40,000 CFM)
 Straight Duct(RL)        0    0   -1   -4   -3   -2   -3   148 / 36 Lined Slab Penetration
 Elbow (In.sq.rct)       -1   -4   -7   -7   -7   -7   -7   148 / 36 Lined Drop to Horizontal Run
     SubSum             100   95   91   86   81   78   75
                         65   63   59   52   42   28   11   Regenerated sound from elbow.
     SubSum             100   95   91   86   81   78   75
 Straight Duct(RL)       -1   -1   -3  -11   -9   -7   -8   72 / 36 Lined Transition
 Elbow (In.sq.rct)       -6  -11  -10  -10  -10  -10  -10   72 / 36 Lined Radius Elbow
     SubSum              93   83   78   65   62   61   57
                         32   31   28   26   22   18   12   Regenerated sound from elbow.
     SubSum              93   83   78   65   62   61   57
 Straight Duct(RL)       -2   -3   -8  -29  -23  -18  -20   72 / 36 Lined Horizontal Run
 Straight Duct(RU1)      -6   -4   -3   -1   -1   -1   -1   72 / 36 Horizontal Run
 Elbow (ul.sq.rct)       -5   -8   -4   -3   -3   -3   -3   72 / 36 Horizontal Run to Rise at Column Line C
     SubSum              80   68   63   32   35   39   33
                         75   69   62   54   46   37   27   Regenerated sound from elbow.
     SubSum              81   72   66   54   46   41   34
 Straight Duct(RU1)      -2   -1   -1    0    0    0    0   72 / 36 Rise at Column Line C
 Elbow (ul.sq.rct)        0   -1   -3   -6   -4   -4   -4   72 / 36 Rise to Horizontal at Column Line C
     SubSum              79   70   62   48   42   37   30
                         72   72   70   64   56   44   29   Regenerated sound from elbow.

 ------------------------------------------------------------------------------------------
 Program User:  Jason Witterman                                   Run Date:     04/07/08
    File Name:  P:\AE482T~1\AH-5R.PDT                             Page Number:  1
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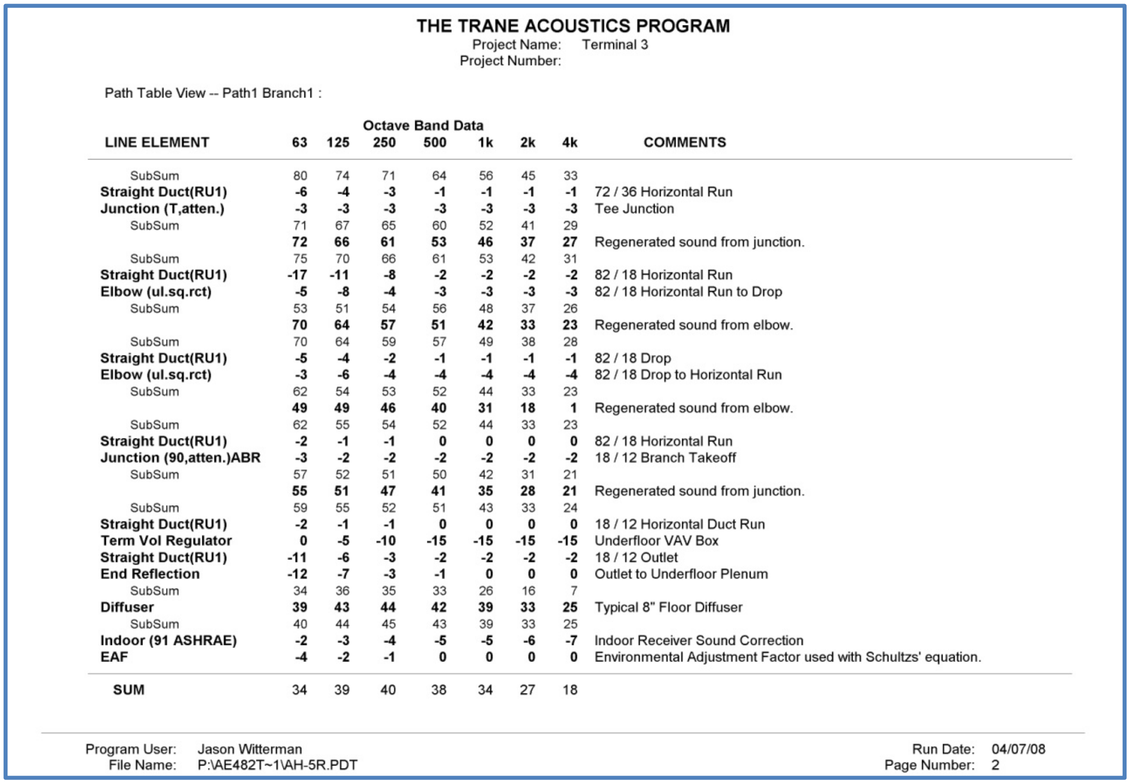

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                         THE TRANE ACOUSTICS PROGRAM
                                   Project Name:  Terminal 3
                                 Project Number:

 Path Table View -- Path1 Branch1 :

                                  Octave Band Data
 LINE ELEMENT            63  125  250  500   1k   2k   4k        COMMENTS
 ------------------------------------------------------------------------------------------
     SubSum              80   74   71   64   56   45   33
 Straight Duct(RU1)      -6   -4   -3   -1   -1   -1   -1   72 / 36 Horizontal Run
 Junction (T,atten.)     -3   -3   -3   -3   -3   -3   -3   Tee Junction
     SubSum              71   67   65   60   52   41   29
                         72   66   61   53   46   37   27   Regenerated sound from junction.
     SubSum              75   70   66   61   53   42   31
 Straight Duct(RU1)     -17  -11   -8   -2   -2   -2   -2   82 / 18 Horizontal Run
 Elbow (ul.sq.rct)       -5   -8   -4   -3   -3   -3   -3   82 / 18 Horizontal Run to Drop
     SubSum              53   51   54   56   48   37   26
                         70   64   57   51   42   33   23   Regenerated sound from elbow.
     SubSum              70   64   59   57   49   38   28
 Straight Duct(RU1)      -5   -4   -2   -1   -1   -1   -1   82 / 18 Drop
 Elbow (ul.sq.rct)       -3   -6   -4   -4   -4   -4   -4   82 / 18 Drop to Horizontal Run
     SubSum              62   54   53   52   44   33   23
                         49   49   46   40   31   18    1   Regenerated sound from elbow.
     SubSum              62   55   54   52   44   33   23
 Straight Duct(RU1)      -2   -1   -1    0    0    0    0   82 / 18 Horizontal Run
 Junction (90,atten.)ABR -3   -2   -2   -2   -2   -2   -2   18 / 12 Branch Takeoff
     SubSum              57   52   51   50   42   31   21
                         55   51   47   41   35   28   21   Regenerated sound from junction.
     SubSum              59   55   52   51   43   33   24
 Straight Duct(RU1)      -2   -1   -1    0    0    0    0   18 / 12 Horizontal Duct Run
 Term Vol Regulator       0   -5  -10  -15  -15  -15  -15   Underfloor VAV Box
 Straight Duct(RU1)     -11   -6   -3   -2   -2   -2   -2   18 / 12 Outlet
 End Reflection         -12   -7   -3   -1    0    0    0   Outlet to Underfloor Plenum
     SubSum              34   36   35   33   26   16    7
 Diffuser                39   43   44   42   39   33   25   Typical 8" Floor Diffuser
     SubSum              40   44   45   43   39   33   25
 Indoor (91 ASHRAE)      -2   -3   -4   -5   -5   -6   -7   Indoor Receiver Sound Correction
 EAF                     -4   -2   -1    0    0    0    0   Environmental Adjustment Factor used with Schultzs' equation.
 ------------------------------------------------------------------------------------------
   SUM                   34   39   40   38   34   27   18

 ------------------------------------------------------------------------------------------
 Program User:  Jason Witterman                                   Run Date:     04/07/08
    File Name:  P:\AE482T~1\AH-5R.PDT                             Page Number:  2
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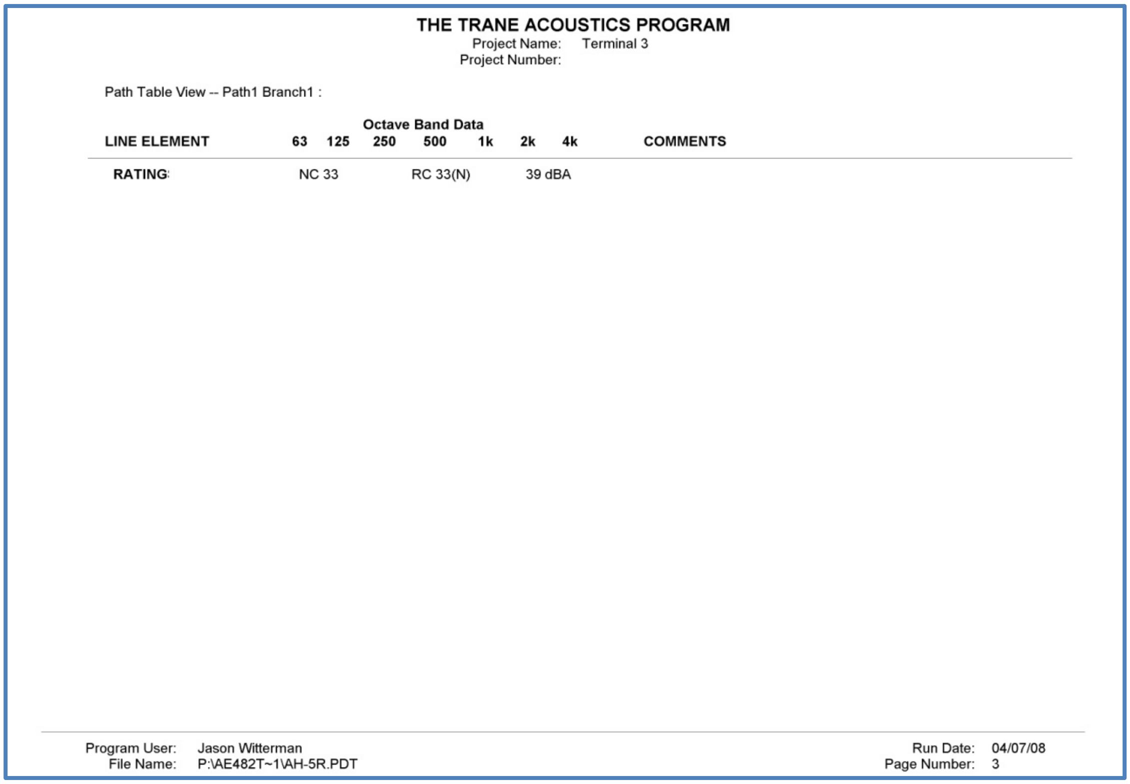
Figure C-1: Trane Acoustics Program Results for AH-5R Supply



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                         THE TRANE ACOUSTICS PROGRAM
                              Project Name:     Terminal 3
                            Project Number:

  Path Table View -- Path1 Branch1 :

                                     Octave Band Data
  LINE ELEMENT            63   125   250    500    1k    2k    4k          COMMENTS

   RATING:                  NC 33            RC 33(N)         39 dBA




  Program User:   Jason Witterman                                        Run Date:    04/07/08
     File Name:   P:\AE482T~1\AH-5R.PDT                               Page Number:    3
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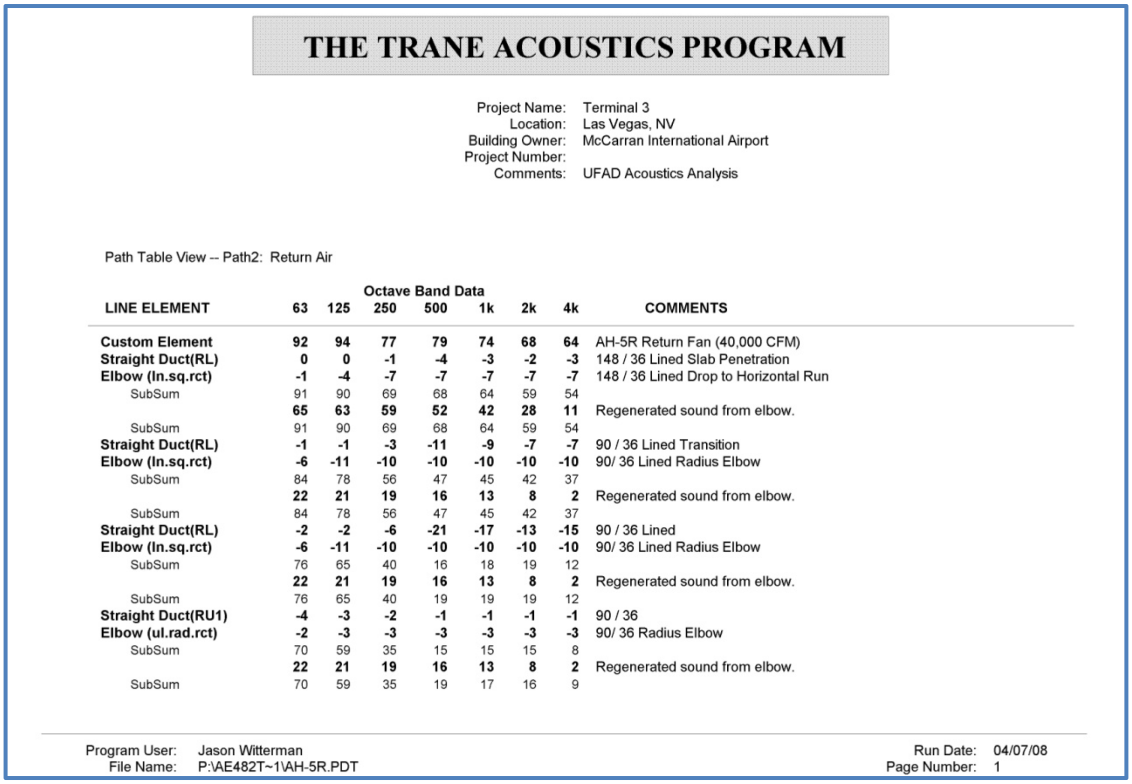
Figure C-1 (Continued): Trane Acoustics Program Results for AH-5R Supply



THE TRANE ACOUSTICS PROGRAM

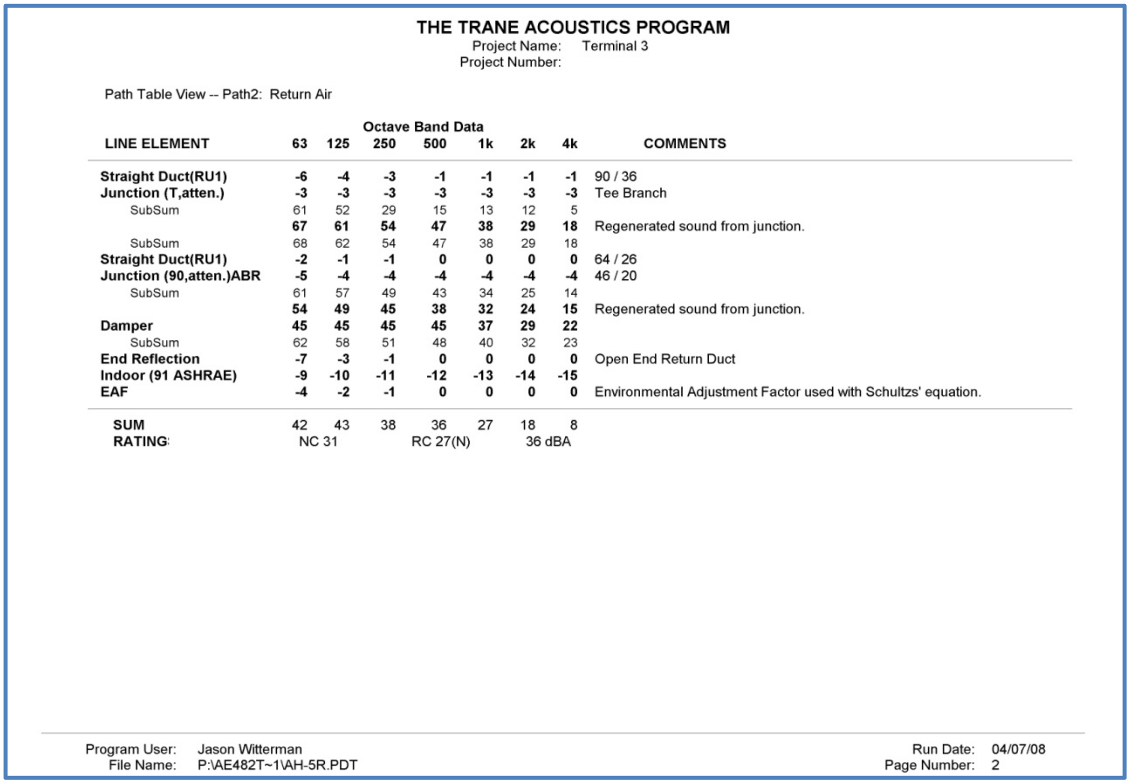
Project Name: Terminal 3
Location: Las Vegas, NV
Building Owner: McCarran International Airport
Project Number:
Comments: UFAD Acoustics Analysis

Path Table View -- Path2: Return Air

Octave Band Data

LINE ELEMENT	63	125	250	500	1k	2k	4k	COMMENTS
Custom Element	**92**	**94**	**77**	**79**	**74**	**68**	**64**	AH-5R Return Fan (40,000 CFM)
Straight Duct(RL)	**0**	**0**	**-1**	**-4**	**-3**	**-2**	**-3**	148 / 36 Lined Slab Penetration
Elbow (ln.sq.rct)	**-1**	**-4**	**-7**	**-7**	**-7**	**-7**	**-7**	148 / 36 Lined Drop to Horizontal Run
SubSum	91	90	69	68	64	59	54	
	65	**63**	**59**	**52**	**42**	**28**	**11**	Regenerated sound from elbow.
SubSum	91	90	69	68	64	59	54	
Straight Duct(RL)	**-1**	**-1**	**-3**	**-11**	**-9**	**-7**	**-7**	90 / 36 Lined Transition
Elbow (ln.sq.rct)	**-6**	**-11**	**-10**	**-10**	**-10**	**-10**	**-10**	90/ 36 Lined Radius Elbow
SubSum	84	78	56	47	45	42	37	
	22	**21**	**19**	**16**	**13**	**8**	**2**	Regenerated sound from elbow.
SubSum	84	78	56	47	45	42	37	
Straight Duct(RL)	**-2**	**-2**	**-6**	**-21**	**-17**	**-13**	**-15**	90 / 36 Lined
Elbow (ln.sq.rct)	**-6**	**-11**	**-10**	**-10**	**-10**	**-10**	**-10**	90/ 36 Lined Radius Elbow
SubSum	76	65	40	16	18	19	12	
	22	**21**	**19**	**16**	**13**	**8**	**2**	Regenerated sound from elbow.
SubSum	76	65	40	19	19	19	12	
Straight Duct(RU1)	**-4**	**-3**	**-2**	**-1**	**-1**	**-1**	**-1**	90 / 36
Elbow (ul.rad.rct)	**-2**	**-3**	**-3**	**-3**	**-3**	**-3**	**-3**	90/ 36 Radius Elbow
SubSum	70	59	35	15	15	15	8	
	22	**21**	**19**	**16**	**13**	**8**	**2**	Regenerated sound from elbow.
SubSum	70	59	35	19	17	16	9	

Program User: Jason Witterman
File Name: P:\AE482T~1\AH-5R.PDT
Run Date: 04/07/08
Page Number: 1



THE TRANE ACOUSTICS PROGRAM
Project Name: Terminal 3
Project Number:

Path Table View -- Path2: Return Air

Octave Band Data

LINE ELEMENT	63	125	250	500	1k	2k	4k	COMMENTS
Straight Duct(RU1)	**-6**	**-4**	**-3**	**-1**	**-1**	**-1**	**-1**	90 / 36
Junction (T,atten.)	**-3**	**-3**	**-3**	**-3**	**-3**	**-3**	**-3**	Tee Branch
SubSum	61	52	29	15	13	12	5	
	67	**61**	**54**	**47**	**38**	**29**	**18**	Regenerated sound from junction.
SubSum	68	62	54	47	38	29	18	
Straight Duct(RU1)	**-2**	**-1**	**-1**	**0**	**0**	**0**	**0**	64 / 26
Junction (90,atten.)ABR	**-5**	**-4**	**-4**	**-4**	**-4**	**-4**	**-4**	46 / 20
SubSum	61	57	49	43	34	25	14	
	54	**49**	**45**	**38**	**32**	**24**	**15**	Regenerated sound from junction.
Damper	**45**	**45**	**45**	**45**	**37**	**29**	**22**	
SubSum	62	58	51	48	40	32	23	
End Reflection	**-7**	**-3**	**-1**	**0**	**0**	**0**	**0**	Open End Return Duct
Indoor (91 ASHRAE)	**-9**	**-10**	**-11**	**-12**	**-13**	**-14**	**-15**	
EAF	**-4**	**-2**	**-1**	**0**	**0**	**0**	**0**	Environmental Adjustment Factor used with Schultzs' equation.
SUM	42	43	38	36	27	18	8	
RATING	NC 31			RC 27(N)		36 dBA		

Program User: Jason Witterman
File Name: P:\AE482T~1\AH-5R.PDT
Run Date: 04/07/08
Page Number: 2

Figure C-2: Trane Acoustics Program Results for AH-5R Return

Appendix D– Access Floor Cost and Scheduling Estimates

This section includes pricing and scheduling information for the access floor to be included in the gate holdroom areas. This information is summarized earlier in the report, but the detailed calculations are provided here for reference. Table D-1 shows the cost calculations for the raised floor while Table D-2 shows the scheduling calculations performed.

Line Number	Item Description	Quantity	Unit	2008 Bare Costs						
				Unit Material Cost	Material Cost	Unit Labor Cost	Labor Cost	Unit Equip Cost	Equip Cost	Total Cost
09 69 13.10	**Access Floors**									
0250	Panels, particle board or steel, 1250# load, no covering; Over 6,000 SF	69,451	SF	$3.61	$250,718.11	$0.95	$65,978.45	$0.00	$0.00	$316,696.56
0600	For carpet covering, add	69,451	SF	$8.30	$576,443.30		$0.00	$0.00	$0.00	$576,443.30
0910	For snap on stringer system, add	69,451	SF	$1.40	$97,231.40	$0.61	$42,365.11	$0.00	$0.00	$139,596.51
1050	Pedestals	17,365	Each	$7.70	$133,710.50	$7.15	$124,159.75	$0.00	$0.00	$257,870.25
--	Minus Existing Carpet	69,451	SF							-$296,555.77
	Total									**$994,050.85**
	Adjusted For Location (0.989)									**$983,116.29**
	Total Per Square Foot	**69,451**	**SF**							**$14.16**

Table D-1: Cost Calculations for Access Floor

Line Number	Item Description	Quantity	Unit	Crew	No. of Crews	Daily Output	Duration [Crew Days]	Labor-Hours	Duration [Labor Hours]
09 69 13.10	**Access Floors**								
0250	Panels, particle board or steel, 1250# load, no covering; Over 6,000 SF	69,451	SF	2 Carp	4.00	640.00	27.1	0.025	1736.28
0600	For carpet covering, add	69,451	SF						
0910	For snap on stringer system, add	69,451	SF	2 Carp	4.00	1000.00	17.4	0.016	1111.22
1050	Pedestals, 6" to 12"	17,365	Each	2 Carp	4.00	85.00	51.1	0.188	3264.62
	Total						**95.57**		**6112.11**

Table D-2: Scheduling Calculations for Access Floor